ASSESSMENT OF PULMONARY FUNCTION OF KENYAN ELITE DISTANCE RUNNERS DURING REST, SUB-MAXIMAL AND MAXIMAL ENDURANCE EXERCISE

BY

FRANCIS MUNDIA MWANGI (MSc)

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DECLARATION

I declare that this thesis is my original work and has not been presented for any study programme in any university.

Signature; _____ Date; 06/11/13

Francis Mundia Mwangi,
Department of Recreation Management and Exercise Science,
Kenyatta University,
Kenya.

SUPERVISORS' APPROVAL

This thesis has been submitted for examination with our approval as the university supervisors:

Signature; _____ Date; 7/11/2013

Vincent Onywera, Ph.D, ISAK 2
Senior Lecturer,
Department of Recreation Management and Exercise Science,
Kenyatta University,
Kenya.

Signature; _____ Date; 7/11/2013

Michael Boit, Ed.D.
Associate Professor,
Department of Recreation Management and Exercise Science,
Kenyatta University,
Kenya.

Signature; _____ Date; Nov 8/2013

William Sheel, Ph.D.
Professor,
School of Kinesiology,
University of British Columbia,
Canada.

DEDICATION

To my dear wife Grace Njambi and my beloved son Evans ‘God is gracious’ Gicheru.

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ABBREVIATIONS AND ACRONYMS

A-aDO_2 - Alveolar to arterial oxygen difference

CO_2 - Carbon dioxide

EIAH - Exercise-Induced Arterial Hypoxemia

extFVL - Tidal flow-volume loop measurement during exercise

Fb - Breathing frequency

FEV_1 - Forced expiratory volume at one second, volume of air that can be expired in one second after a maximal inspiration

FEV_1/FVC - Ratio between FEV_1 and FVC

FRC - Functional Residual Capacity, volume of gas contained in the lung after a normal expiration

FV - flow-volume

FVC - Forced vital capacity, volume change between a forced maximal inspiration to total lung capacity and a maximal expiration to residual volume

FVL - Flow Volume Loop (a graphical display of the subject inspiratory and expiratory effort with volume on the axis and flow on the horizontal display)

HCO_3 - Bicarbonate ions

IC - Inspiratory capacity; the volume change from full expiration to maximal inspiration

IVC - Inspiratory Vital Capacity; the volume change between a maximal expiration to residual volume and a full inspiration to total lung capacity

m.a.s.l. - meters above sea level

MEP - Maximal Expiratory Pressure test

MFVL - Maximal flow-volume envelope/loop

MIP - Maximal Inspiratory Pressure test

MVV - Maximal Voluntary Ventilation, a measure of the maximum amount of air that can be inhaled and exhaled in one minute, measured in litres per minute

O_2 - Oxygen

$PaCO_2$ - Partial pressure of arterial carbon dioxide

PaO_2 - Partial pressure of arterial oxygen

PAO_2 - Partial pressure of alveolar oxygen

PEF - Peak expiratory flow, maximum flow generated during expiration performed with maximal force and started after a full inspiration

pH - Acid-base status

priorRMF - Induced respiratory muscle fatigue

RER – Respiratory exchange ratio

RGC - Respiratory gas collection systems

RMF - Respiratory muscle fatigue

RV - Residual Volume, volume that remains in the lungs after a maximal expiration, cannot be measured by spirometry

SaO_2 - Arterial oxygen saturation (determined mainly by PaO_2 but also by a pH- and temperature-induced shift of the HbO_2 dissociation curve)

tHb -Total Hemoglobin

VC - Vital capacity; the volume change between a full inspiration and a maximal expiration

VE - Minute ventilation

Vt - Tidal volume

VT - Ventilation Threshold

%MHR - Percentage of maximum heart rate

OPERATIONAL DEFINITIONS OF TERMS

This section provides definition of terms as they have been use in this study.

Endurance Exercise; a sustained sub-maximal to maximal intensity running on a treadmill taking 12 minutes or more

Endurance performance; Doing a sustained sub-maximal to maximal intensity running and putting up best effort to attain optimum score in terms of speed or distance covered in a given time 12 minutes or more

Exercise-Induced Arterial Hypoxemia; reduced arterial oxygenation / sharp decrease in arterial partial pressure of oxygen resulting from endurance running (Mild exercise-induced arterial hypoxemia; a fall in SaO_2 to below 95 - 92%, Moderate hypoxemia; 92 – 88%, Severe hypoxemia; values below 88%) (Dempsey & Wagner, 1999; Yamaya *et al.,* 2002)

Hyperventilation; Exercise-induced hyperpnea / deep and faster breathing which is associated with endurance exercise.

Hypoxemia; deficient oxygenation of the blood/ inadequate oxygen in the blood / decreased partial pressure of oxygen in blood -specifically less than 60 mmHg (8.0 kPa) or causing hemoglobin oxygen saturation of less than 95%.

Kenyan Elite Distance Runners; Athletes of Kenyan ancestry who have participated in international events such as Olympic, World Championships or Commonwealth Games in middle and long distance races

Lung Capacity; ability of the lungs to hold and move respiratory air / gas volumes

Maximal Endurance Exercise; sustained running at an intensity beyond which the individual cannot tolerate (endurance running intensity at which the runner cannot sustain for three minutes)

Normoxia; normal oxygen conditions at the testing location (Nairobi is 1,661m [5,450ft] above sea level)

Predicted / Reference values; Values from empirical data that are used as norms to evaluate data for given variables, such as the prediction equations from the National Health and Nutrition Examination Survey (NHANES III)

Pulmonary Function; operations of the lungs and related body structures, including ventilation and gaseous exchange between lungs and blood

Pulmonary Function Parameters; Characteristics related to lung functions as measured by spirometry system (ML 311, ADInstruments, Australia), Pneumotachograph (HR800L, HansRudolph, USA), respiratory gasses (oxygen and carbon dioxide) analyzers (17625, 17630 Vacumed, Ventura, California, USA), and arterial blood gases analyser (ABL80 FLEX)

Sub-Maximal Endurance Exercise; sustained running at an intensity ranging between moderate and the maximum that can be tolerated by an individual (about 85 to 95% of maximum heart rate)

Test to Exhaustion; running assessment procedure until the participant is unable to keep up with the pace, or to volitional termination or symptomatic stoppage by the attending physician. RER of 1.1 or above should be reached for the value to be taken as truly maximal.

ABSTRACT

Kenyan middle and long distance runners have performed extraordinarily well, dominating the world over the past four decades. The factors that contribute to their prowess in endurance races are not yet determined. Pulmonary limitations to endurance performance have been reported among non-Kenyan runners but the extent Kenyan runners experience or overcome these limitations had not been investigated. The purpose of this study was to assess pulmonary function parameters of Kenyan elite runners in relation to endurance exercise performance and compare with predicted values. Fifteen (10 male, 5 female) purposively selected elite Kenyan runners were instrumented in baseline spirometry and an incremental treadmill test to exhaustion at a moderate altitude (1,600 m.a.s.l.). Spirometric variables measured included forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), forced expiratory volume in one second as a proportion of forced vital capacity (FEV_1/FVC) and maximum inspiratory pressure (MIP). Respiratory measures obtained during treadmill test included tidal volume (Vt), breathing frequency (Fb), minute ventilation (VE), oxygen consumption (VO_2), carbon dioxide production (VCO_2) and respiratory exchange ratio (RER). Arterial blood gases (ABG) data; arterial oxygen partial pressure (PaO_2), arterial oxygen saturation (SaO_2), arterial partial pressure of carbon dioxide ($PaCO_2$), alveolar to arterial oxygen partial pressure difference (A-aDO_2) and acidosis (pH) were obtained from blood samples taken from radial artery at the end of every exercise stage via indwelling cannula. Repeated measures ANOVA and *t* tests were run to examine the various measurements at different exercise intensities using statistical package for social sciences. One sample *t* test on participants' spirometric variables' percentage of predicted values showed that they were not significantly different from commonly used predicted values ($p > .05$). Absolute VO_2 peak values for males (3.50±.26) and females (2.26±.26) [L/min] were significantly higher than the predicted values ($p = .001$). Relative VO_2 max for males (64.4±4.9) and females (48.1±4.9) [ml/kg/min] rated superior and excellent respectively on cardio-respiratory fitness classification norms. ABG data showed that the runners experienced only moderate levels of exercise-induced arterial hypoxemia (EIAH) (SaO_2 = 89.4±4.6%[male], 91.5±2.2%[female], 89.9±4.1[total]% and A-aDO_2 = 24.5±4.7[male], 20.1±10.7[female], 23.39±6.39[total] mmHg) at maximal endurance exercise. Respiratory compensation (partial) for metabolic acidosis was evident ($PaCO_2$ = 34.15±3.44 mmHg, pH = 7.30±.08[total]). Bicarbonate ions (HCO_3) recorded the most consistent decline and highest effect size (Eta sqd = .724) while change in oxygen content in the blood (CaO_2) recoded the least (Eta sqd = .072). Stepwise regression showed that VE was the most significant predictor of VO_2 and speed at sub-maximal exercise level. The study concluded that most Kenyan distance runners' baseline pulmonary function values are comparable to commonly used reference values. However, the runners' respiratory system is able to cope with demands of superior oxygen consumption during endurance running. The runners experience moderate level hypoxemia during sub-maximal and maximal endurance exercise. Strategies to alleviate excessive acidosis are recommended for improving performance during endurance training and competitions. Further investigations are needed to determine the source of the differences in pulmonary function among distance runners, and the effects on endurance race performances.

CHAPTER ONE: INTRODUCTION

1.1. Background of the Problem

For slightly over the past four decades (since 1968), athletes from East African region have dominated international distance running events (Larsen, 2003; Noakes, 2001; Onywera, Scott, Boit & Pitsiladis, 2006; Prommer *et al.,* 2010; Saltin, 2003; Scott & Pitsiladis, 2007). This is especially the case for Kenyan runners. For example, save for the two Olympics Games that Kenya boycotted (1976 and 1980), they have not lost the steeplechase event since 1968. Moreover, runners from this East African nation account for 91 of the 100 best times ever in the steeplechase (International Association of Athletics Federations [IAAF], 2012). Similar statistics exist for other middle and long distance running events including the marathon where seven of the top-10 best times have been achieved by Kenyan athletes (IAAF, 2012). Noakes (2001) noted that no international sport has ever been dominated by athletes from one country to the extent the Kenyans have done in international competitions from 800 m race to the marathon, winning between 40 and 50% of all medals.

The reason as to why the Kenyans and other East African athletes perform so extraordinarily well in endurance races is a question that has inspired considerable interest, speculation and debate amongst athletes, coaches and academics (Onywera *et al.,* 2006; Saltin, 2003; Scott & Pitsiladis, 2007; Prommer, *et al.,* 2010). Those interested in understanding the dominance of these athletes have wondered whether the 'secret' can be found in the socialization experiences and lifestyles of Kenyan children (e.g. the effects of running to school as children), impacts of living and growing up at high altitude, and/or to the nutrition/diet of these athletes (Fudge *et al*., 2006; Onywera *et al*., 2006; Saltin, 2003). Others suggest that Kenyans benefit from

genetic advantages over groups in other regions of the world (Scott & Pitsiladis, 2007). However, the extent to which various factors contribute to Kenyan runners dominating the field remains as yet to be determined (Onywera *et al*., 2006; Pitsiladis, Onywera, Geogiades, O'Connell & Boit, 2004; Scott *et al.,* 2005; Scott & Pitsiladis, 2007).

Pulmonary limitations to endurance exercise performance have been identified by several studies (Dempsey, Sheel, Haverkamp, Babcock & Harms, 2003; Romer, Lovering, Haverkamp, Pegelow & Dempsey, 2006; Romer, Haverkamp, Lovering, Pegelow & Dempsey, 2006; Sheel *et al*., 2001). These include exercise-induced arterial hypoxemia resulting from inadequate hyperventilation, excessive widening of the alveolar to arterial O_2 difference, and metabolic acidosis. It is known to be characterized by reduced oxygen saturation in arterial blood (SaO_2 < 95 %) and/or excessive widening of the alveolar to arterial oxygen difference ($AaDO_2$ > 24 mmHg) (Dempsey & Wagner, 1999; Plowman & Smith, 1997). High fatiguing levels of respiratory muscle work also limits performance as these muscles get priority (due to their critical function) over locomotor muscles for more blood. This is known to occur as a sympathetic reflex which effectively reduces blood flow (thus reduced oxygen delivery) to working locomotor muscles, with more blood directed to respiratory muscles (Dempsey *et al*., 2003; Plowman & Smith, 1997; Romer *et al*., 2006b; Sheel *et al*., 2001).

According to Dempsey *et al.,* (2003), the adaptability of the pulmonary system structures to habitual physical training is substantially less than is in other links in the O_2 transport system. This leads to structures such as lung's airways, diffusion surface, and/or chest-wall musculature being not fully adapted to the demand for

maximal O_2 transport in some highly trained individuals, implications of which are the pulmonary limitations to exercise cited above (Dempsey *et al.,* 2003; Dempsey & Wagner, 1999). The current study focused on investigating whether Kenyan elite distance runners have superior pulmonary capabilities or/and the extent to which they experience these pulmonary limitations during exercise, matters that had not been investigated thus far.

1.2. Statement of the Problem

While it is known that elite runners have an extremely high ability to use oxygen during exercise (Larsen, 2003; Saltin, 2003), pulmonary limitations to exercise performance related to oxygen delivery and carbon dioxide removal during endurance running have been reported among non-Kenyan elite runners (Dempsey & Wagner, 1999). These include exercise-induced arterial hypoxemia related to inadequate hyperventilation, excessive widening of the alveolar to arterial O_2 difference, and acidosis which effectively limits performance by limiting oxygen available in locomotor muscles to produce energy (Plowman & Smith, 1997; Romer *et al*., 2006 *a* and *b;* Sheel *et al*., 2001; Taylor & Romer, 2008). It is not known if Kenyan runners who have dominated distance running events in the world have enhanced ability to get oxygen from air to the blood, or the extent to which they experience or overcome these pulmonary limitations to endurance exercise performance. This was considerable knowledge gap which the proposed study sought to address.

There was scarcity of data on elite Kenyan runners' lungs and pulmonary function thus far. In addition, the extent to which various factors such as altitude, diet, genetics or training effects contributes to Kenyan runners excelling in the field of distance races is not fully determined despite several studies focussing on various aspects of

Kenyan endurance athletes (Onywera *et al*., 2006; Pitsiladis *et al*., 2004). The study therefore examined pulmonary capacity and functions of elite Kenyan runners which are involved in getting oxygen from the air into the blood and removal of carbon dioxide for optimal endurance performance during sub-maximal and maximal endurance exercise.

1.3. Purpose of the Study

The purpose of this study was to assess pulmonary function parameters of Kenyan elite distance runners at rest and during sub-maximal and maximal endurance exercise. This was to enable the researcher determine whether the Kenyan elite distance runners have an enhanced ability to move and transfer respiratory gasses from air to the blood stream (and vice versa) for better aerobic function in the working muscles during endurance running exercise. It was postulated that favourable spirometric, ventilatory and gaseous exchange parameters may attenuate pulmonary limitations to endurance performance such as EIAH, excessive A-aDO_2 and metabolic acidosis.

1.4. Research Objectives

The main research objective was to determine if Kenyan elite distance runners have enhanced pulmonary function which would lead to enhanced O_2 delivery and/or removal of CO_2 for better endurance performance, and whether their pulmonary function parameters are related to their performance during sub-maximal and maximal endurance exercise.

The study was guided by the following specific research objectives:

1. To evaluate baseline spirometric values (IVC, FVC, FEV_1, FEV_1/FVC, PEF, MIP) and exercising respiratory values (IC, Vt, Fb, VE, VO_2 max, RER) of Kenyan elite distance runners against predicted / reference values.
2. To evaluate ventilatory status of Kenyan elite distance runners in relation to acid-base status (metabolic or respiratory acidosis) (as indicated by pH, $PaCO_2$ and HCO_3 values) during sub-maximal and maximal endurance exercise.
3. To investigate whether Kenyan distance runners experience exercise-induced arterial hypoxemia (SaO_2 < 95 % and/or A-aDO_2 > 24 mmHg) during sub-maximal and maximal endurance exercise, and the extent.
4. To determine the relationship between pulmonary function parameters and performance among Kenyan elite middle and long distance runners.

1.5. Research Questions

The study was guided by the following research questions:

1. How do the baseline spirometric values (IVC, FVC, FEV_1, FEV_1/FVC, PEF, MIP) and exercising respiratory values (IC, Vt, Fb, VE, VO_2 max, RER) of Kenyan elite distance runners rate against predicted / reference norms?
2. Do Kenyan elite distance runners experience inadequate hyperventilatory response to acid-base status (as indicated by pH, $PaCO_2$ and HCO_3 values) during sub-maximal and maximal endurance exercise?
3. To what extent do Kenyan elite distance runners experience exercise-induced arterial hypoxemia (SaO_2 < 95 % and/or A-aDO_2 > 24 mmHg) during sub-maximal and maximal endurance exercise?

4. Is there significant correlation between pulmonary function parameters and performance during sub-maximal and maximal endurance exercise among Kenyan elite distance runners?

1.6. Significance of the study

This work sheds light on pulmonary function capacity of Kenyan elite distance runners in relation to endurance performance. The study determined the extent to which pulmonary function of Kenyan elite distance runner is affected by some pulmonary limitations to distance running during sub-maximal and maximal treadmill running intensities. It also helped understand how Kenyan runners' lung capacity and function compares with norms, as well as determines the pulmonary parameters which are most critical in their endurance exercise performance. Practitioners in this area can leverage on this information to improve training and performance in middle and long distance running and other endurance exercises and sports.

There was capacity building on the research materials and the procedures involved. The study also informs pedagogical and training practices in exercise science on the relationship between pulmonary function and endurance running performance, and the information gaps yet to be fully addressed. It provides information on possibility of using respiratory training sessions in training programmes to improve performance in sub-maximal endurance running. Information on possible legal ways of alleviating metabolic acidosis by endurance athletes with potential to improve performance is also elucidated.

1.7. Delimitations of the Study

The study was delimited to assessment of pulmonary capacity and function of Kenyan elite distance runners and its possible influence on performance. The participants were on their usual/normal diet (without coffee, drugs or alcohol intake) 24 hours prior to and throughout the test period. Their running techniques were expected to remain relatively the same across the treadmill test trials. A familiarisation session on treadmill running was conducted prior to testing period for those who had no experience in running on a treadmill. The tests and measurements were carried out in a performance laboratory where testing and environmental conditions (such as air quality, distractions and weather) were relatively under control.

1.8. Limitations of the Study

The study did not directly assess the influence of skill on performance (efficiency of technique of running) and blood lactate, being variables that can affect performance in test trials (Bassett & Howley, 2000; Mwangi, Wanderi, Wamukoya, Onywera & Gitonga, 2011). However, it considered speed and the percentages of VO_2 max utilised by the athletes, as well as their ventilatory threshold, variables that can infer to running efficiency and blood lactate tolerance. Energy status of the participants was neither assessed nor controlled, but it was assumed that their normal diet provided optimal energy level during the testing period. The other limitation is that endurance exercise performance was not measured directly but rather estimated / inferred from speed attained in endurance treadmill running tests.

1.9. Assumptions of the Study

The study assumed that:

1. The participants were highly motivated to complete the tasks involved in the study. However, they were cheered on and encouraged to give their maximum effort.
2. The participants communicated their health and other physiological status to the researcher accurately and honestly.
3. Minor environmental changes (of which were minimal) such as weather changes did not significantly affect the results.
4. The participants were at optimal nutritional/energy status during the testing time.

1.10. Theoretical Framework

Among the three major determinants in long distance running performance is utilization of high oxygen uptake capacity, the others being running economy and blood lactate variables (Bassett & Howley, 2000; Fulton, Murphy, Moore & Spurrs, 2001). The study is based on Presentation Theory which recognises the ability of the body's cardiovascular system to deliver oxygen to active tissues that are involved in endurance exercise as the critical determinant of human aerobic capacity. It is also in line with Utilization theory which maintains that VO_2 max is determined by the body's ability to utilize the available oxygen (considering that excessive acidosis may affect aerobic respiration). Mackenzie (2010) states that the physical limitations that restrict the rate at which energy can be released aerobically are dependent upon the chemical ability of the muscular cellular tissue system to use oxygen in breaking down fuels, and the combined ability of cardiovascular and pulmonary systems to transport the oxygen to the muscular tissue system. These constitute the two theories on how the various physiological factors combine to determine the rate of aerobic energy production: Utilization Theory and Presentation Theory.

1.11. Conceptual Framework

The study was based on the concept of pulmonary function capacity for endurance performance. While it has been reported that several measures of lung capacities are correlated to performance in endurance races (Pringle, Latin & Berg, 2005), existence of pulmonary limitations to endurance performance has been pointed out by several studies (Dempsey & Wagner, 1999; Miyachi & Shibayama, 1992; Romer *et al.*, 2006a and b; Sheel *et al*., 200; Taylor & Romer, 2008). Evidence presented by studies suggests that exercise-induced arterial oxygen desaturation / hypoxemia may occur in highly trained endurance athletes and my be accompanied by excessive widening of the alveolar to arterial oxygen difference, inadequate hyperventilation and excessive metabolic acidosis (Dempsey & Wagner, 1999; Miyachi & Shibayama, 1992; Plowman & Smith, 1997; Romer *et al.,* 2006a). The proposed study postulated that Kenyan elite middle and long distance runners who have performed extraordinarily well are not adversely affected by these conditions. This is from the fact that the more the athletes are affected by these limitations, the poorer their performance in sub-maximal and maximal endurance incremental exercise test, high sub-maximal speed or race time, other factors being constant.

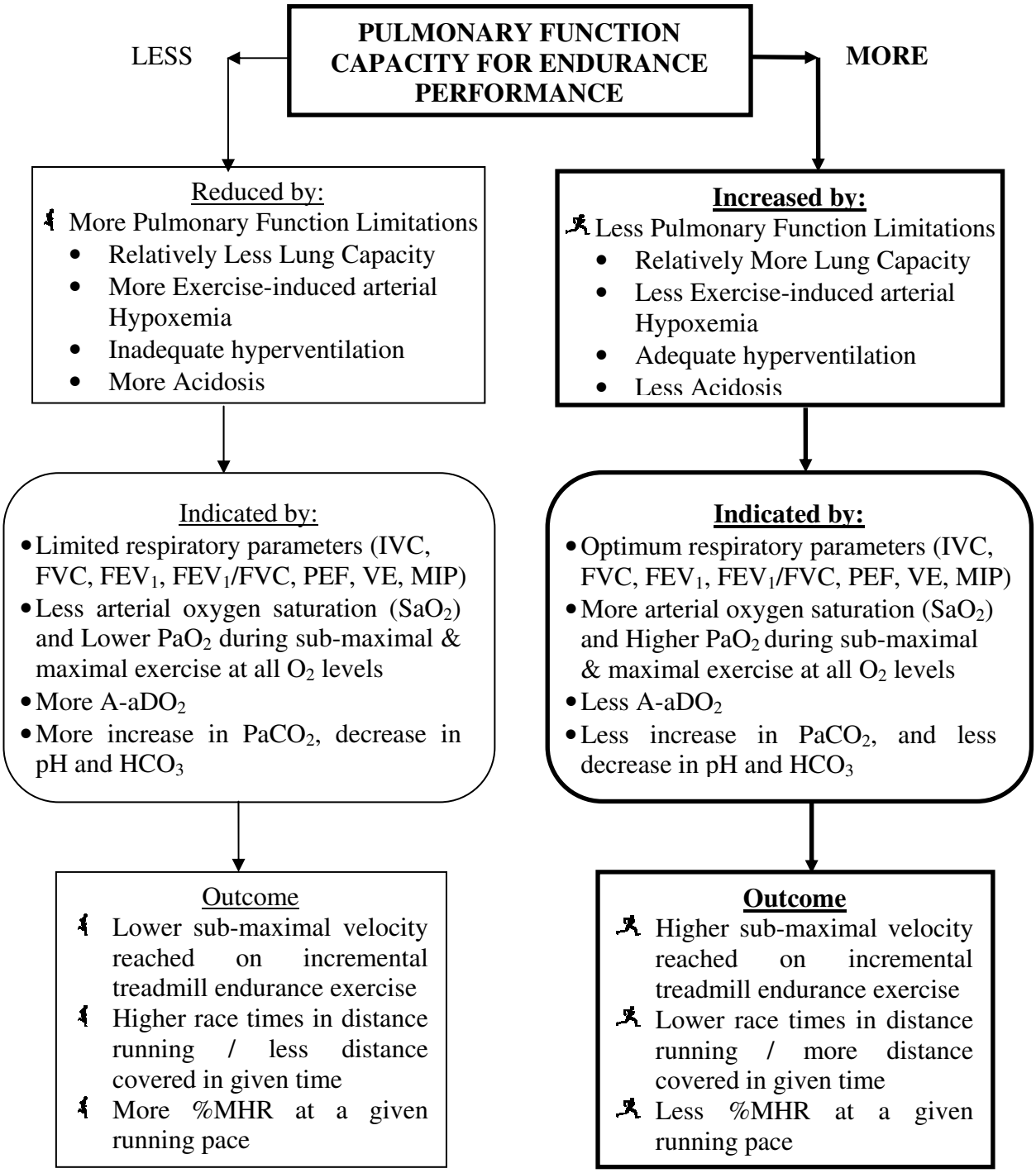

Figure 1.1: Conceptual framework model showing factors involved in pulmonary capacity for endurance performance (Model is researcher's own position on the issue, based on information from Dempsey and Wagner (1999), Miyachi and Shibayama (1992), Plowman and Smith (1997), Pringle *et al.* (2005), and Sheel *et al.* (2001).

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

This section reviews literature on the relationship between distance running performance and aerobic processes, lung capacity and function, pulmonary limitations to endurance exercise and studies on Kenyan distance runners. Literature related to the relevant measurements reliability is also covered.

2.2. Oxygen Delivery and Utilisation during Distance Running

Distance running performance relies to a large extent on aerobic capacity of the runner. The aerobic energy system which is utilised during distance running requires constant supply of oxygen. Therefore, any factor that affects oxygen delivery and / or utilisation will affect performance in distance running. Mackenzie (2010) states that there are two theories that attempts to explain the determinants of human aerobic capacity; Utilization Theory and Presentation Theory. The Utilization Theory maintains that VO_2 max is determined by the body's ability to utilize the available oxygen whereas the Presentation Theory maintains it is the ability of the body's cardiovascular system to deliver oxygen to active tissues that is critical.

Several studies have sought to demonstrate which of the two is true. According to Saltin and Calbet (2006), in healthy humans VO_2 max at sea level is limited by oxygen delivery to the locomotor muscles rather than on the mitochondrial oxidative capacity. The authors indicate that oxygen delivery (and thus VO_2 max) depends on the ability of the cardio-respiratory system (i.e., lungs, heart, and blood) to transport and distribute appropriately O_2 to the active motor units, rather than on the mitochondrial oxidative capacity, which exceeds widely the maximal O_2 supply in

human skeletal muscles during all exercise intensities (Saltin & Calbet, 2006; Bassett & Howley, 2000). However, VO_2 max on its own may not be accurate predictor of endurance running performance. But the velocity (vVO_2 max) and duration ($tlimvVO_2$ max) that an athlete can operate at their VO_2 max (-measures of efficiency and of blood lactate tolerance respectively) provides better indication of performance (Mackenzie, 2010). This means that factors that may affect oxygen utilisation (such as high blood lactate levels or low tolerance level) may limit endurance performance as well. Logical thinking is that, the highest percentage of VO_2 max that can be maintained over time is more indicative of success than the maximal value which cannot be maintained for long period of time (Warpeha, 2003).

2.2.1. Lung Function during Endurance Exercise

Role of human lungs includes gaseous exchange oxygen, carbon dioxide and pH regulation. During endurance exercise, the ventilation demands increases a great deal in line with exercise intensity (Haff & Dumke, 2012; Plowman & Smith, 1997). Distance running performance has been shown to correlate with lung capacity and some other pulmonary function parameters by some studies (Adegoke & Arogundade, 2002; Fatemi *et al.,* 2012; Pringle *et al.,* 2005), while some other studies show no significant associations (Amonette & Dupler, 2002; Knechtle and Kohler, 2008). In a study by Pringle *et al*. (2005), the relationship between selected measures of respiratory function and capacity and performance in a 10 km race was investigated. Thirty-five subjects completed a local 10 km road race. They were measured for the following variables: inspiratory capacity (IC), forced vital capacity (FVC), functional residual capacity (FRC), total lung capacity (TLC), maximal voluntary ventilation in 12 sec) (MVV), maximum inspiratory pressure (MIP), maximum expiratory pressure (MEP), and forced expiratory volume in 1 second (FEV_1). Results showed a significant ($p <$

0.05) negative relationship between run time and FVC (r = -0.39), MVV (r = -0.52), and IC (r = -0.35). Using stepwise multiple regression analysis it was found that MVV explained 27.0% of the variance in 10 km run time, FVC explained 15.2% and IC explained 12.3%. Results of this study suggested that selected measures of lung capacities were related to performance in a 10 km race. The study seems to support the presentation/delivery theory (oxygen delivery system as the vital limiting factor to endurance performance) even though correlative evidence does not mean causation. The current study was based on the oxygen presentation/delivery theory and sought to establish the status and relationships of the key variables involved in the same among Kenyan distance runners.

Miyachi and Shibayama (1992) conducted a study to determine the propriety of the hypothesis that the pulmonary capacity for oxygen transport cannot meet superior demands imposed by cardiovascular system in highly trained endurance athletes, and endurance training primarily causes adaptation in the skeletal muscles and in the systemic cardiovascular system, with little change in the pulmonary system. Sixteen highly trained endurance athletes (ET) and thirteen untrained subjects (UT) volunteered to participate in the experiments involved. All subjects performed the four experiments; 1) the highest oxygen uptake (peak VO_2) during incremental cycle exercise where ventilation (VE), ventilatory equivalent for O_2 (VE/VO_2) and arterial O_2 saturation (SaO_2) at peak VO_2 were observed, 2) the maximal voluntary ventilation (MVV) for 30 sec at rest, 3) the pulmonary diffusing capacity for CO (DLCO) and expressed per unit of alveolar lung volume (KCO) at rest by the single breath method, and 4) the ventilatory response to hypercapnia (S) at rest by re-breathing method. The peak VO_2 of ET (66.7 ml/min/kg) was significantly (30.8%) higher than UT (52.4 ml/min/kg), and VE/VO_2 and SaO_2 of ET (29.3 and 93.7%, respectively) were

significantly lower than UT (34.6 and 95.8%). There were no differences in VE, MVV, DLCO, and S between two groups (Miyachi & Shibayama, 1992). The study indicates favourable differences in values related to oxygen delivery to consumption ratio and no difference in the other ventilatory and diffusion values between the trained and untrained athletes in cycling. The current study sought to investigate the relationships between variables related to oxygen delivery and performance related variables among Kenyan endurance runners.

Ventilatory constraint during exercise has been reported by researchers and authors (Dempsey, McKenzie, Haverkamp & Eldridge, 2008; Johnson, Beck, Zeballos & Weisman, 1999). According to Johnson *et al*. (1999), measurement of the tidal flow-volume (FV) loop measurement during exercise (extFVL) and plotting it within the maximum flow-volume loop (MFVL) can help to determine the degree of ventilatory limitation. A flow sensing device is use to measure the MFVL at rest and FV responses during exercise, typically in conjunction with standard gas-exchange measurements. Two or three MFVLs are produced at rest prior to exercise in addition to several maximal inspiratory maneuvers from functional residual capacity. Exercise tidal FV responses (typically two to five) are obtained toward the end of each work intensity / stage, followed by repeat inspiratory capacity (IC) maneuvers. The IC measurements are used to place the tidal loops within the MFVL by aligning the maximal inspiratory volume points at total lung capacity (TLC). Varied information has been extracted from the extFVL plotted within the MFVL, from simple visual information to actual quantification of various indices of VE constraint. Indices such as tidal volume (Vt) relative to IC or vital capacity in conjunction with breathing frequency to help describe the degree of VE constraint (Dempsey *et al*., 2008; Johnson *et al*., 1999). The VE constraint and the responses of respiratory system in

relation to oxygen delivery mentioned above points towards pulmonary function limiting the extent to which endurance performance can be supported and sustained. These limitations are addressed in the next section.

2.3. Pulmonary Limitations to Endurance Exercise

Existence of pulmonary limitations to endurance performance has been pointed out by several studies. These includes exercise-induced arterial hypoxemia (EIAH) which is characterised by low levels of arterial blood oxygen saturation and/or excessive widening of the alveolar to arterial oxygen difference, inadequate hyperventilation and metabolic acidosis (Dempsey & Wagner, 1999; Sheel *et al*., 2001). Another closely related pulmonary limitation is the highly fatiguing levels of respiratory muscle work which effectively reduce blood flow to locomotor muscles via a sympathetically mediated reflex (Romer *et al.*, 2006b; Taylor & Romer, 2008). The current study focused on pulmonary function status among Kenyan runners and its association with endurance running performance.

2.3.1. Exercise-Induced Arterial Hypoxemia and Endurance Performance

Exercise-Induced Arterial Hypoxemia (EIAH) is broadly considered as reduced arterial oxygenation, which may result from a fall in PaO_2 (and thus in SaO_2 also), a fall in SaO_2 from a rightward shift of the O_2 hemoglobin dissociation curve (without a fall in PaO_2) or from a combination of these processes (Dempsey & Wagner, 1999; Plowman & Smith, 1997). Evidence presented by studies (Amann, Romer, Subudhi, Pegelow & Dempsey, 2007; Dempsey *et al.,* 2003; Dempsey & Wagner, 1999; Miyachi & Shibayama, 1992; Romer *et al.,* 2006a) suggests that exercise-induced arterial O_2 desaturation may occur in highly trained endurance athletes. This is associated with excessive widening of the alveolar to arterial O_2 difference,

inadequate hyperventilation and metabolic acidosis. It indicates inefficiency in respiration and limits endurance performance in highly trained athletes (Dempsey *et al*., 2008; Plowman & Smith, 1997; Ward, 2007). Potential mechanisms of EIAH include relative alveolar hypoventilation, ventilation-perfusion inequality, diffusion limitation and right-to-left shunt (Dempsey *et al.,* 2008; Guenette & Sheel, 2007; Nielsen 2003).

According to Dempsey and Wagner (1999), the response to maximal incremental load typically consists of a gradual widening of the alveolar to arterial oxygen difference (A-aDO_2) from 5–10 Torr at rest to 20–25 Torr at maximal exercise for normal healthy humans. It is usually accompanied by a ventilatory response that rises proportionally up to 60% VO_2 max, then out of proportion to increasing O_2 uptake (and CO_2 production) in moderately heavy through maximum exercise (Haff & Dumke, 2012; ATS/ACCP, 2003), thereby raising alveolar PO_2 (and reducing arterial PCO_2) sufficiently to prevent arterial hypoxemia. However, alveolar to arterial oxygen difference values of as much as 30 Torr and reduction of SaO_2 by as much as 15% below resting levels have been reported among fit subjects during exercise near sea level (Dempsey & Wagner, 1999; Plowman & Smith, 1997). The excessive alveolar-to-arterial PO_2 difference (A-aDO_2) (>25–30 Torr) and inadequate compensatory hyperventilation (arterial PCO_2 >35 Torr) commonly contribute to EIAH, as do acid- and temperature-induced shifts in O_2 hemoglobin dissociation at any given arterial PO_2 (Dempsey *et al*., 2008; Ward, 2007; Dempsey & Wagner, 1999). The consequences of EIAH on exercise performance are said to relate to its negative influence on maximal O_2 uptake (VO_2 max) and impairment of oxygen delivery (Lu, Coneys, LaBossiere & Sharma, 2011), and possibly the brain hypoxic

effects on effort perception leading to increased perceived exertion (Amann *et al.,* 2007).

These studies on EIAH show that exercise-induced arterial O_2 desaturation may occur in highly trained endurance athletes and hamper/limit performance due to less oxygen delivery to the muscles. It is imperative then to find out the status of Kenyan elite athletes in this regard, with their exemplary performance in the field, a task the current research study sought to accomplish.

2.3.2. Acid-base Balance and Endurance Exercise Performance

Human body physiological processes occur within a limited range of acid-base status. Blood plasma is a slightly alkaline aqueous (water) solution, with a normal pH range of 7.35 to 7.45. Plasma acidemia is a pH below 7.35 (although this is still alkaline), and plasma alkalemia is a pH above 7.45. Plasma pH levels below 6.9, and above 7.8, are fatal. Levels below 7.35 and above 7.45 can result in physical symptoms, psychological changes, and performance deficits. The body regulates pH by using two opposing system to balance pH. If the pH is out of balance because of a respiratory disorder, it will be the renal system that makes the corrections to balance the pH. Conversely, if the renal system is to blame for the pH disorder, the respiratory system will have to compensate. Compensation is thus the attempt by the body to maintain homeostasis by correcting the pH to its normal level. It may not always be complete. There are times such as during maximal exercise when the imbalance is too large 9resulting from lactic acid generated by anaerobic respiration) for compensation to restore the pH to normal. This is called partial compensation (Jindal, Singh & Agarwal, 2008; Woodruff, 2009).

The component of the respiratory system that balances the pH is the dissolved carbon dioxide (CO_2) that is produced by cellular processes and removed by the lungs. An increase of 10 mmHg in $PaCO_2$ over the normal resting value of 40mmHg reduces pH from the normal resting value of 7.40 to 7.35, while a drop of 10 mmHg ($PaCO_2$= 30 mmHg) raises pH to 7.50 (Jindal *et al.,* 2008). The respiratory system balances the pH by increasing or decreasing the respiratory rate and/or depth, thereby manipulating the CO_2 level. Fast and deep breathing 'blows off' carbon dioxide, while slow and shallow breathing 'retains' CO_2. (Jindal *et al.,* 2008; Woodruff, 2009).

The component of the renal system that balances the pH is the dissolved bicarbonate (HCO_3) produced by the kidneys. The kidneys also help control pH by eliminating hydrogen (H+) ions. The way the two systems (respiratory and renal systems) interact is through the formation of carbonic acid (H_2CO_3). Movement through the carbonic acid system is fluid and constant, where water (H_2O) molecules combines with CO_2 and form carbonic acid. If necessary, carbonic acid (H_2CO_3) can then break up to form hydrogen ions (H+) and bicarbonate (HCO_3). This buffer system works in both direction, balancing back and forth to achieve and maintain a normal pH /acid-base balance in the body (Jindal *et al.,* 2008; West, 2008; Woodruff, 2009). The renal system will reacts to changes in metabolic activity within the body such as anaerobic metabolism which leads to production of lactic acid, of which will bind (or use up) available bicarbonate ions (HCO_3) (and therefore, the HCO_3 level is an indicator of metabolic acid-base balance). The system will reabsorb/retain HCO_3 ions from the renal filtrate (Jindal *et al.,* 2008; West, 2008; Woodruff, 2009). However, renal system is slow and therefore, mostly it is the respiratory system which regulates the blood pH during maximal exercise.

A study by Jubrias *et al.,* (2003) tested the hypothesis that acidic pH inhibits oxidative ATP supply during exercise in hand (first dorsal interosseus, FDI) and lower limb (leg anterior compartment, LEG) muscles. Oxidative flux and estimated mitochondrial capacity were measured using the changes in creatine phosphate concentration (PCr) and pH as detected by 31P magnetic resonance (MR) spectroscopy during isometric exercise and recovery. The highest oxidative ATP flux in sustained exercise was about half the estimated mitochondrial capacity in the LEG (0.38±0.06 vs. 0.90±0.14 mM ATP/s), respectively), but was similar at the estimated capacity in the FDI (0.61±0.05 vs. 0.61±0.09 mM ATP/s), respectively). During sustained exercise at a higher contraction rate, intracellular acidosis (pH < 6.88) prevented a rise in oxidative flux in the LEG and FDI despite significantly increased ADP. The researchers tested whether oxidative flux could increase above that achieved in sustained exercise by raising ADP (> 0.24 mM) and avoiding acidosis using burst exercise. This exercise raised oxidative flux (0.69±0.05 mM ATP/s) to nearly twice that found with sustained exercise in the LEG and matched (0.65±0.11 mM ATP/s) the near maximal flux seen during sustained exercise in the FDI. Thus both muscles reached their highest oxidative fluxes in the absence of acidosis. These results show that acidosis inhibits oxidative phosphorylation in vivo and can limit ATP supply in exercising muscle to below the mitochondrial capacity. This study demonstrates that acidosis affects endurance performance. However, ventilatory and gas exchange parameters were not addressed, and Kenyan distance runners have not been investigated in this regard. The current study sought to undertake these tasks.

2.4. Studies on Kenyan Distance Runners

Several researchers have studied several aspects of Kenyan endurance athletes (Fudge *et al*., 2006; Onywera *et al*., 2006; Onywera, Kiplamai, Tuitoek, Boit & Pitsiladis,

2004; Pitsiladis *et al*., 2004; Saltin, 2003; Scott *et al*., 2005; Scott *et al*., 2009; Scott & Pitsiladis 2007). The section below covers a summary of some of the studies:

Saltin (2003) compared Kenyan and Scandinavian runners by scrutinizing their physiological makeup and assessing the trainability of novice runners from both countries. The researcher used 12 Scandinavian runners who had trained for two weeks in Kenya at high altitudes (2000 m.a.s.l.) and 13 Kenyan runners who lived and trained at high altitude. Muscle biopsy procedures were done on the runners from their Vastus Lateralis and Gastrocnemius muscles. It was found that there was no significant difference in muscle size and slow twitch and fast twitch fibres component. However, the Kenyan runners were found to have higher number of capillaries. There were similar levels of citrate synthase (CS) activity among the two groups of runners but higher level (20% more) of 3-hydroxyacyl-CoA dehydrogenase (HAD) activity on the part of Kenyan runners. The ratio of lactate dehydrogenase (LDH) isoform 1-2 to isoform 4-5 in Scandinavian runners was increased by altitude training due to lowered LDH 4-5, to the level observed in the Kenyan runners. Saltin's group (as cited in Holden, 2004) also observed that, compared with the Danes, the thinner calves of Kenyans, on average, have 400 grams less flesh in each lower leg. The further the weight is placed from the center of gravity, the more energy it takes to move it. Fifty grams added to the ankle will increase oxygen consumption by 1%. This translates into 8% energy savings for Kenyans to run a kilometer. The group concluded that the dominance of Kenyan endurance runners could be attributed to the differences in physique and muscle makeup, which is a strong genetic component. This study focused on genetical, morphological, training factors and O_2 utilization. But the role of oxygen delivery and CO_2 removal in distance running performance were not addressed, tasks the current study set out to undertake.

Researchers have investigated the Kenyan distance runners with the International Center for East African Running Science, based at the University of Glasgow, Scotland (Scott *et al*., 2005; Scott & Pitsiladis 2007). The researchers collected DNA samples from 221 national Kenyan athletes (N), 70 international Kenyan athletes (I), and 85 members of the general Kenyan population (C) to assess the extent to which genetic factors relate to East African distance running phenomenon. The insertion (I) rather than deletion (D) of a 287 bp fragment in the human angiotensin converting enzyme (ACE) gene is associated with lower circulating and tissue ACE activity and with endurance performance amongst Caucasians. Blood samples were obtained from C and assayed for circulating ACE activity. ACE I/D genotype was determined, as was genotype at A22982GD which has been shown to associate more closely with ACE levels in African subjects than the I/D polymorphism. ACE I/D and A22982G genotypes explained 13 and 24% of variation in circulating ACE activity levels (p = 0.034 and p <0.001 respectively). I/D genotype was not associated with elite endurance athlete status (df = 4, chi sqd = 4.1, p = 0.39). In addition, genotype at 22982 was not associated with elite endurance athlete status (df = 4, chi sqd = 5.7, p = 0.23). Nor was the A allele at 22982, which is associated with lower ACE activity, more prevalent in N (0.52) or I (0.41) relative to C (0.53). The study concluded that ACE I/D and A22982G polymorphisms are not strongly associated with elite endurance athlete status amongst Kenyans.

More analyses compared frequencies of mitochondrial DNA (mtDNA) haplogroups found in elite Kenyan athletes with those in the general Kenyan population (Scott *et al.*, 2009). Classification of mtDNA haplogroups were done by sequencing 340 bases of hypervariable section (HVS I) and by genotyping known restriction sites. Frequency differences between groups were assessed using exact tests of population

differentiation. Results showed that the haplogroup distribution of national (p = .023) and international athletes (p < .001) differed significantly from controls, with international athletes showing a greater proportion of L0 haplogroups (C = 15%, N = 18%, I = 30%) and lower proportion of L3 haplogroups (C = 48%, N = 36%, I = 26%). Conclusions was that International athletes differed in their mtDNA haplogroup distribution relative to the general Kenyan population, in that they display excess of L0 haplogroups and a dearth of L3 haplogroups. Following the findings, the researchers suggest that mtDNA haplogroups are influential in elite Kenyan distance running, although they did not rule out population stratification compounding the results. These studies focused on possible linkage of genetical factors associated with O_2 utilization (and energy production) and elite Kenyan endurance athletes. However, the role of oxygen delivery and removal of carbon dioxide in distance running performance were not elucidated.

Favorable environmental conditions such as altitude, diet and anthropometry, in addition to the motivational and unfavorable socio-economic factors were proposed as possible reasons for the unsurpassed achievements of Kenyan distance runners (Onywera *et al*., 2006). However, the fact that the majority of internationally successful Kenyan runners originate from the Kalenjin, a small Kenyan ethnic group that accounts for approximately 13% of the total Kenyan population (Kenya National Bureau of Statistics [KNBS], 2013) points to a possible genetic component. The group concluded that, despite the speculation that African athletes have a genetic advantage, there is no genetic evidence yet (Onywera *et al*., 2006; Pitsiladis *et al*., 2004; Scott *et al*., 2005; Scott & Pitsiladis 2007).

Onywera *et al*. (2004) analyzed food and macronutrient intake of elite Kenyan runners and compared it to recommendations for endurance athletes. Estimated energy intake (EI: 2987 ±293 kcal) was lower than energy expenditure (EE: 3605 ±119 kcal) and body mass was reduced over the 7-day intense training period (BM: 58.9 ±2.7 kg vs. 58.3 ±2.6 kg). Diet was high in carbohydrate and low in fat. Protein intake matched recommendations for protein intake. Fluid intake was modest and mainly in the form of water and tea. The researchers concluded that the diet met most recommendations for endurance athletes for macronutrient intake, but the athletes may need to modify energy balance and fluid intake to enhance performance. Other related study reported Kenyan endurance runners to be in negative energy balance during training and prior to competition (Fudge *et al*., 2006). The researchers pointed out that a negative energy balance would result in a reduction in body mass, which, when combined with a high carbohydrate diet, would have the potential in the short term to enhance endurance running performance by reducing the energy cost of running.

These studies on Kenyan and East African endurance runners are focused on genetical, cultural, dietary, as well as training factors in relation to the athletes' performance. None of the studies focused on the role of gas delivery and exchange systems in distance running performance, a task the current research study set out to undertake.

2.5. Studies on Respiratory Functions among Kenyans

A study by Orie, (1999) was conducted to compare the normal respiratory function values in young Kenyans with those reported for regional African neighbours and Caucasians. Forced expiratory volume in one second (FEV_1), forced vital capacity

(FVC) and peak expiratory flow rate (PEFR) were measured in a non-randomized sample of young indigenous Kenyans and the values were compared with those of age-matched regional African neighbours (Ethiopians and South Africans) and Caucasians (Australians). Eighty eight apparently healthy young Kenyan university students (64 males, 20-25 years and 24 females, 19-23 years) were examined. The results showed that the mean values (males versus females) were FEV_1; 3.95 ± 0.07 versus 2.97 ± 0.08 [L], FVC; 4.31 ± 0.08 versus 3.19 ± 0.09 [L], and PEFR; 586.30 ± 8.54 versus 438.30 ± 8.55 [L/min]. The values for females were 25-26% less than those for males. The expiratory ratios (FEV_1/FVC*100) were 92.22 ± 0.60% and 93.44 ± 0.61% for males and females respectively, well within normal range. The FEV_1, FVC and PEFR for both males and females correlated positively with heights. The study concluded that the results were comparable to values reported for age-matched regional neighbours (Ethiopians and South Africans) but were lower than those reported for Australian Caucasians. Noting that normal lung function values serve as important references for diagnosis of respiratory disorders, and that the values vary with race and human settlements and are affected by environmental, nutritional, genetic, and anthropometric factors, the study pointed out the need for the Kenyan population to have its own local reference values.

The above study assessed respiratory values of general student population in a Kenyan university. The population may not have been homogeneous as the students may come from various backgrounds. The study is also silent on endurance training and performance as a possible factor that may influence relate to respiratory values, an issue that the current study aimed to address.

2.6. Studies on Respiratory Functions among Kenyan Endurance Athletes

To better understand the Kenyan endurance athletes' dominance in the marathon, Tam *et al.* (2012) tested ten top-level Kenyan marathon runners (KA) plus nine European controls (EC, of similar performances to KA). The researchers measured maximal oxygen consumption (VO_2 max) and the energy cost of running (C_r) on track during training camps at moderate altitude. At each incremental running speed, steady-state oxygen consumption (VO_2) was measured by telemetric metabolic cart, and lactate by electroenzymatic method. The speed requiring VO_2 ¼ VO_2 max provided the maximal aerobic velocity (v_{max}). The energy cost of running was calculated by dividing net VO_2 by the corresponding speed. The speed at lactate threshold ($v_{\theta AN}$) was computed from individual La_b versus speed curves. The sustainable VO_2 max fraction (F_d) at $v_{\theta AN}$ ($F_{\theta AN}$) was computed dividing $v_{\theta AN}$ by v_{max}. The F_d for the marathon (F_{mar}) was determined as $F_{mar} = 0.92\ F_{\theta AN}$. Overall, VO_2 max (64.9 ± 5.8 vs. 63.9 ± 3.7 ml kg^{-1} min^{-1}), v_{max} (5.55 ± 0.30 vs. 5.41 ± 0.29 m s^{-1}) and C_r (3.64 ± 0.28 vs. 3.63 ± 0.31 J kg^{-1} m^{-1}) resulted the same in KA as in EC. In both groups, C_r increased linearly with the square of speed. $F_{\theta AN}$ was 0.896 ± 0.054 in KA and 0.909 ± 0.068 in EC; F_{mar} was 0.825 ± 0.050 in KA and 0.836 ± 0.062 in EC (NS). Accounting for altitude, running speed predictions from present data are close to actual running performances, if $F_{\theta AN}$ instead of F_{mar} is taken as index of F_d. In conclusion, both KA and EC did not have a very high VO_2 max, but had extremely high F_d, and low C_r, equal between them. The dominance of KA over EC cannot be explained on energetic grounds.

This study measured maximal oxygen consumption, sustainable VO_2 and the energy cost of running among Kenyan marathon runners and European controls. It however

did not investigate oxygen and carbon dioxide delivery processes and their possible implications to endurance performance among Kenyan runners. These are tasks that the current study aimed at accomplishing.

Seeking to understand the physiological reasons underlying the superiority of East Africans runners worldwide, Prommer *et al.* (2010) conducted a study whose purpose was to evaluate the total hemoglobin mass (tHb-mass) and blood volume (BV) of Kenyan runners and their adaptation to near sea level. The variables were determined in 10 male Kenyan runners (10-km best time = 28:29±00:27 min) residing at an altitude of 2090 m over the course of a 6-wk training camp at sea level. Their values were compared with those of elite German runners (10-km best time = 30:39±00:24 min) (at near sea level). Results showed that Kenyans are characterized by significantly lower body mass (Kenyans = 57.2±7.0 kg; Germans = 66.5±6.3 kg) and body mass index (Kenyans = 18.5±0.9; Germans = 20.4±0.9). Relative tHb-mass (Kenyans = 14.2±1.0 g/kg; Germans = 14.0±0.7 g/kg) and BV (Kenyans = 101.9±4.5 mL/kg; Germans = 99.6±5.8 mL/kg) were similar in both groups but were decreased in Kenyans during the stay at near sea level (absolute tHb-mass from 813±90 g to 767±90 g, $p < .001$; BV from 5828±703 mL to 5513±708 mL, $p < .01$). Relative VO_2 max was similar in both groups (Kenyans 71.5±5.0 mL/kg/min; Germans 70.7±3.7 mL/kg/min). The study concluded that the oxygen transport of the blood cannot explain the superior endurance performance of Kenyan runners. Most measured parameters are in the same range as those of elite German runners, and tHb-mass even deteriorates after an adaptation to near sea level. This study investigated the oxygen carrying capacity of blood in Kenyans compared to German runners but did not investigate how the variables interact with pulmonary variables at maximal incremental exercise, task the current study hoped to address.

The studies described above measured maximal oxygen consumption, energy cost of running and the oxygen carrying capacity of blood in Kenyans compared to European controls. They however did not investigate pulmonary processes involved in oxygen delivery and carbon dioxide removal process and their possible influence on endurance performance among Kenyan runners. The current study endeavored to bridge these gaps by focusing on baseline spirometric measures, exercise respiratory and arterial blood gas measurements in relation to endurance running exercise performance.

2.7. Studies on Measurement Reliability

The reliability of test data taken with subjects wearing respiratory gas collection (RGC) systems on exercise test performance has been studied. The effects of using facemask and flow sensor have been found to be insignificant for short duration incremental treadmill exercise tests. In a study by Clark (2008) to evaluate the difference in incremental exercise test performance with and without a RGC system, twenty moderately active males performed two progressive treadmill tests to volitional exhaustion. In random order subjects ran with (MASK) or without (NO-MASK) a RGC facemask and flow sensor connected to a gas analyzer. Descriptive data (mean ± SD) were determined for all parameters. The Wilcoxon signed rank test for paired differences was used to assess mean differences between MASK and NO-MASK conditions. The results showed that; exercise time to exhaustion, peak treadmill speed, peak blood lactate concentration, peak heart rate and rating of perceived exertion (RPE) were not different ($p > .05$) between MASK and NO-MASK conditions. The study concluded that incremental exercise test performance is not adversely affected by RGC and analysis equipment, at least in short duration progressive treadmill exercise. Respiratory gas analyses during exercise testing for

diagnostic, performance assessment or training prescription purposes would be unaffected by RGC systems. The current study involved use of RGC system and thus values were reliably obtained.

ABL80 FLEX (Radiometer-Copenhagen, Denmark) is a portable blood gas analyzer for blood gas (pH, PCO_2, PO_2), electrolyte (Na, K, Cl), ionized calcium, and hematocrit testing. A study by Nichols, Karim and Arabadjief, (2008) evaluated the ability of ABL80 FLEX's quality control system (QC^3) to detect potential sources of error that may affect results. External, surrogate quality control samples were analyzed 3 times a day for 30 days to determine the equivalence of external and onboard quality control. In addition, the analyzer was challenged with air bubbles during control and specimen analysis and introduction of haemolysed specimens. External, surrogate sample controls failed on 6 occasions when an incorrect temperature was input into the analyzer. These failures were acceptable once proper temperature correction was applied to the external control samples. QC^3 appropriately detected air in the sensors, open inlet port, disconnected sensors, and problems with reagent sensor and solution packs. Grossly haemolysed specimens resulted in no sample carryover or long-term effects on the sensor. The QC^3 internal control system appropriately detected common sources of operator and analyzer failure on the ABL80 FLEX blood gas analyzer. QC^3 was better at detecting analyzer problems compared with external, surrogate quality control by continuously detecting potential errors automatically. In the current study, ABL80 FLEX's quality control system was run every time the sensor was changed (after 50 samples analyses) as per the operation guidelines.

CHAPTER THREE: METHODOLOGY

3.1. Introduction

This section highlights on the research design, target population and study location, sample size and sampling procedures, instrumentation and data collection protocol, as well as pretesting. It also covers the statistical analyses, logistical and ethical considerations.

3.2. Study Design

The study was carried out in an experimental research design, specifically the Repeated Measures (Within-Subject) design. Laboratory-based experiments were done where measures of expiratory flow limitation, ventilation and gas exchange were examined at rest and during treadmill running. Pulmonary function parameters and heart rate were the dependent variables. Independent variables were the different exercise intensities (exercise stages) in the incremental treadmill endurance running tests.

3.3. Target Population and Location of the Study

The study targeted Kenyan elite distance runners who are in good training form. It was carried out at Kenyatta University's human performance laboratory at the department of Recreation Management and Exercise Science. This facility is the best suitable for this type of study as it has most of the equipment required to measure the variables involved in the study. The facility was boosted with additional apparatus/equipment by the study collaborators from University of British Columbia. The knowledge so generated is being disseminated by the researcher and the members of this and related departments / institutions.

3.4. Sampling Procedures and Sample Size

The athletes were recruited purposively through their coaches or direct contact. Inclusion into the study required being 18-40 years of age, past participation in international events such as Olympic, World Championships or Commonwealth Games in middle and long distance races, normal lung function as defined by the forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV_1), and no evidence of past or present pulmonary pathology such as asthma or chronic obstructive pulmonary disease (COPD). Athletes were to be excluded from the study if they have been previously diagnosed with pulmonary or cardiovascular pathologies (i.e. asthma, hypertension, cardiac arrhythmias), or if any contraindications existed for the procedures involved in the study tests. In addition, athletes were to be excluded if they do not have two full generations of Kenyan ancestry preceding them. Full verbal assent and written consent were obtained from all subjects prior to experimentation.

Fifteen healthy (10 male; 5 female), elite Kenyan runners were recruited to participate in this study. This number of subjects is beyond the number (4) that which is expected to give an acceptable power of the test ($\geq .80$; $\beta \leq .20$) as recommended by many authors (Lenth, 2001; Vincent, 1995) as calculated through Power Analysis and Sample Size software (PASS) (Hintze, 2005). The sample size determination considered the repeated measures (within-subject) research design (subjects measured 3 to 5 times –at rest, sub-maximal and maximal exercise), and mean ± SD values (95±4) from empirical data on arterial oxygen saturation at $\alpha \leq .05$. According to IHF (2008), a change of ± 3-4% in oxygen saturation values is clinically significant.

3.5. Instrumentation and Data Collection Protocol

Prior to instrumentation and baseline testing sessions, each participant included in the study signed an informed consent form. Then they completed a health screening questionnaire, a physical activity readiness questionnaire (PAR-Q), and a Running history questionnaire (see Appendix II). No participant was identified as either having any health problem or meets any of the study's exclusion criteria or tests contraindication, otherwise he/she would have been excluded from further experimentation. After the inclusion criteria were met, the participants were instrumented on two days. On Day 1 they performed basic anthropometry measurements**.** On Day 2, resting physiological measurements were taken and participants performed baseline spirometric tests, and a treadmill test to exhaustion. Details of these procedures and instruments used are outlined below.

3.5.1. Basic Anthropometry Measurements

Basic anthropometric measures were taken to establish the general body type and composition of the participants using procedures recommended by ISAK (Marfell-Jones, Olds, Stewart and Carter, 2006). Digital scale (Seca aura 807, Leicester) was used for weight measurements, stadiometer (Height Measure SE001, Leicester) for height, skinfold calliper (Slimguide Body Care, England) for skinfold measurements, sliding calliper (Rosscraft Cambell 10, USA) for breaths, segmometer (Rosscraft Segmometer 4, Canada) for segments, and tape (Rosscraft Anthrotape ORC, USA) for girths.

3.5.2. Resting Physiological Parameters

After a 10-15 minute period of resting in a sited position, ventilation (tidal volume and frequency), respiratory gases, blood pressure, heart rate, and arterial blood

parameters were measured. These were done using the following equipment/apparatus; Spirometer system (ML 311, ADInstruments, Australia), Pneumotachograph (HR800L, HansRudolph, USA), respiratory gasses (oxygen and carbon dioxide) analyzers (17625 and 17630, Vacumed, Ventura, California, USA), automated blood pressure system (BPM-100, VSM Medtech Ltd, Vancouver, Canada), pulse oximetry (8600, Nonin Medical, Plymouth, MN) and blood gas analyser (ABL 80 Flex COOX, Copenhagen, Denmark). The measurements were taken while the participant is resting in upright sitting position.

3.5.3. Baseline Spirometry Tests

Participants performed 3-6 forced vital capacity test maneuvers. These involved breathing on a turbine of spirometer system, taking several normal breaths followed by a large inspiration to total lung capacity and a full forceful expiration to residual volume. From this maneuver, values for the forced vital capacity (FVC), the forced expiratory volume in 1 second (FEV_1) and peak expiratory flow rates (PEF) were taken (see Appendix IVa). Maximal Inspiratory (MIP) was also taken to measure the strength of the respiratory muscles using a pressure manometer (Raytech Instruments, Vancouver, BC). The measurement required the subject to breathe in as hard as possible for at least 1 second at functional residual volume (see Appendix IVb).

3.5.4. Treadmill Test, Respiratory and Arterial Blood Gas Assessments

After a 5 minute warm-up at a speed of 5-8 $kmhr^{-1}$, the participants began the running test on a treadmill (h/p/cosmos COS10199, Germany) at a starting speed of 14 kmh^{-1} (9 kmh^{-1} for women) and no elevation. Every three minutes the treadmill speed was increase by 1 km hr^{-1} until exhaustion, as recommended by several studies (Bentley, Newell & Bishop, 2007; Hoffman, 1999; Jones, 1998). The participants were made to

breathe through a mouthpiece of spirometer system with nose clip fixed, allowing the measurement of ventilation to be made. In addition, the respired gases were analyzed such that the amount of carbon dioxide produced and oxygen consumed was determined. Heart rate was measured and monitored using Polar heart rate monitor (S610i, Polar Electro, Kempele, Finland) (see Appendix IVc).

Arterial blood samples were taken from radial artery at rest and at the end of every exercise level/stage via an indwelling arterial cannula (see Appendix IVd). This was done by an authorised trained practitioner (medical doctor), to provide blood specimens for direct measurement of partial pressures of carbon dioxide ($PaCO_2$) and oxygen (PaO_2), hydrogen ion activity (pH), total hemoglobin (tH), and bicarbonate ions (HCO_3^-). This was done using blood gas analyser. Data was recorded through a data acquisition system (PowerLab/16SP, ADInstruments, Colorado Springs, CO) and on protocol sheets (see Appendix IVf-h). The measures (pH, $PaCO_2$, PaO_2) were corrected for body temperature using nomogram developed from Henderson-Hasselbalch equation (Ashwood, Kost and Kenny, 1983) and Rosenthal factor (pH decreases by 0.0147 per degree Celsius) (see Appendix V).

3.6. Statistical Analyses

Statistical Package for Social Sciences (SPSS) software (v. 17) was used to perform the statistical procedures: Intraclass coefficient was used to determine reliability of the data and test procedures. Descriptive statistics (mean and standard deviation) were used to summarize participants' characteristics. Repeated measures ANOVA and repeated measures/paired and dependent *t* tests were used to examine the various measurements at different time points / intensities of exercise. Paired and dependent *t* tests were also used to compare the recorded values to the predicted / norm values.

Pearson correlation and multiple regression analyses were used to determine the relationships between pulmonary function parameters and performance of the runners on the graded treadmill trials. PowerLab software was also used to perform and generate outputs on the test parameters.

3.7. Pretesting

Study instruments were pretested in a session involving two purposively selected endurance athletes. The pretesting involved spirometric and exercise respiratory gas assessment procedures. This was conducted for the purposes of familiarizing the researcher and the research assistants with the test procedures, as well as assessing the efficacy and accuracy of test instruments. The tests instruments and measuring procedures of the variables involved were appropriately refined before proceeding to the collection of the research data.

3.8. Logistical and Ethical Considerations

Permission to carry out the research and ethical review approval were sought from the relevant government institutions/organs (the Ministry of Higher Education: National Council for Science and Technology and Kenyatta University Ethics Review Committee). The study collaborators also obtained ethical review approval from University of British Columbia. All the participants gave verbal assent and signed written informed consent after reading and getting explanation about the research prior to experimentation (see Appendix I). The information obtained during the study is being handled in confidence and used for academic purpose only. Disposal procedures for biomedical materials were followed in discarding the research wastes at Kenyatta University Health Unit's incinerator.

CHAPTER FOUR: RESULTS AND INTERPRETATION

4.1. Introduction

This chapter presents research findings arranged in following order; participants' characteristics, descriptive data analysis, further analyses of research variables and interpretation, summary of addressed research questions, and spurious relationships. Further discussion on results interpretation is presented in the next chapter.

4.2. Participants Characteristics

Characteristics of the fifteen participants who took part in the study are given in the following subsections, including demographic, ethnic, basic anthropometric and training attributes:

4.2.1. Demographic and Basic Anthropometric Data

The gender distribution of the participants was ten male athletes and five female athletes. Their age categories and basic anthropometric characteristics are shown in Table 4.1 and Table 4.2 respectively. The age of the participants was 25.40 ± 4.64 (Mean ± SD) (n = 15) (see Table 4.2) and is within the range at which endurance athletes are in their prime (Schulz & Curnow, 1988), while the BMI value is typical of values reported for Kenyan distance runners (Kong & Heer, 2008).

Table 4.1: Cross tabulation of participants' gender by age category (n = 15).

Participant's gender		Participant's age category [yrs]			
		18 - 22	23 - 27	28 - 32	Total
	Male	1	4	5	10
	Female	3	1	1	5
Total		4	5	6	15

Table 4.2: Basic anthropometric characteristics of the participants (n = 15).

Anthropometric Attribute	Mean		Std. Dev.
	Statistic	Std. Err.	Statistic
Age [yrs]	25.40	1.20	4.64
Body height [cm]	169.28	1.87	7.23
Body weight [kg]	52.06	1.31	5.06
Body mass index	18.17	.34	1.33
Waist circumference [cm]	66.98	.88	3.42

The participants' ethnic subgroup distribution is shown in Table 4.3 below. It shows that the sample was a representative group given that majority of elite Kenyan distance runners come from these ethnic groups, as established by Onywera *et al.* (2006).

Table 4.3: Participant's ethnic subgroup (n = 15).

Ethnic subgroup	Frequency	Percent	Cumulative Percent
Kipsigis	4	26.7	26.7
Nandi	8	53.3	80.0
Marakwet	2	13.3	93.3
Turkana	1	6.7	100.0
Total	15	100.0	

4.2.2. Training Attributes

The participants' training attributes are presented in Table 4.4. There is high training volume and frequency, typical of successful endurance training as reported by several authors (Karp, 2007; Kong & Heer, 2008). This can also be attributed to the fact that endurance training requires more duration (of moderate to high intensity) and less recovery time in contrast with strength and speed training.

Table 4.4: Training characteristics of the participants (*n* = 15).

Variable	Mean		Std. Dev.
	Statistic	Std. Err.	Statistic
Distance to school from home [km]	2.20	.14	.56
Exercise frequency per week	5.33	.16	.62
Running/training frequency per week	4.93	.12	.46
Duration of competitive running [yrs]	4.43	.50	1.95
Average training distance (in a training session) [km]	11.20	1.29	5.00
Weekly training mileage [km]	99.07	10.92	42.30
Longest distance run so far [km]	20.20	3.51	13.61

4.3. Baseline Spirometry Data

Baseline Spirometry data was obtained from fifteen participants (10 male and 5 female athletes), all of whom successfully completed spirometry maneuvers involved in the tests. The variables tested were; IVC, FVC, FEV_1, FEV_1/FVC, PIF, PEF and MIP. The value recorded are summarised and analysed in the following subsections:

4.3.1. Descriptive Baseline Spirometry Values

The values are summarised in descriptive measures of mean and standard deviation in Table 4.5 below, the former being a measure of central tendency, and the latter a measure of dispersion. Status of these values is addressed in the next sub-section.

Table 4.5: Descriptive statistics (Mean ± SD) on spirometric variables of the participants (*n* = 15).

Spirometric variable	Mean		Std. Dev.
	Statistic	Std. Err	Statistic
Subject's peak inspiratory flow [L/s]	4.22	.43	1.65
Subject's peak expiratory flow [L/s]	7.28	.72	2.80
Subject's forced vital capacity [L]	3.64	.19	.72
Subject's forced expiratory volume in one second [L]	3.01	.19	.74
Subject's forced expiratory volume in one second as a proportion of forced vital capacity [%]	85.34	1.73	6.69
Subject's maximum inspiratory pressure	79.76	4.88	18.91

4.3.2. Dependent *t* Test Analyses of Baseline Spirometry Values

One sample / dependent *t* test was used to compare the baseline spirometric values against their corresponding predicted values. Prediction equations from the National Health and Nutrition Examination Survey (NHANES III) for African American were used as presented by Hankinson, Odencrantz and Fedan (1999). These reference standards are based on measurements of normal subjects of similar age, height, and race (see Appendix III). Prediction equations from local study by Orie (1999) yielded significantly higher values than those recorded by the current study. The *t* statistic values and the corresponding *alpha* values for each of the spirometric variable are shown in Table 4.6 below. The same values with male and female athletes analysed separately are shown in Table 4.7 and Table 4.8 respectively.

Table 4.6: One sample *t* test on participants spirometric variables' percentage of predicted values (n = 15).

Spirometric variable	Test Value = 100			
	t	*df*	Sig. (2-tailed)	Mean Diff.
Peak expiratory flow as percentage of predicted [%]	-2.585	14	.022	-16.234
Forced vital capacity as percentage of predicted [%]	-2.960	14	.010	-8.529
Forced expiratory volume in one second as percentage of predicted [%]	-2.792	14	.014	-11.726
Forced expiratory volume in 1 second as a proportion of FVC, as percentage of predicted [%]	.090	14	.929	.2028

The results shows that male spirometric values are not significantly different from predicted values, while those of female athletes are significantly lower than predicted values except the proportion of forced expiratory volume in one second to forced vital capacity (FEV_1/FVC) which showed no significant difference from predicted values for both male (p = .281) (see Table 4.7) and female athletes (p = .270) (see Table 4.8).

Table 4.7: One sample / dependent *t* test on male participants spirometric variables' percentage of predicted values ($n = 10$).

Spirometric variable	Test Value = 100			
	t	*df*	Sig. (2-tailed)	Mean Diff.
Peak expiratory flow as percentage of predicted [%]	-1.164	9	.274	-8.118
Forced vital capacity as percentage of predicted [%]	-1.726	9	.118	-6.890
Forced expiratory volume in one second as percentage of predicted [%]	-1.437	9	.184	-7.094
Forced expiratory volume in 1 second as a proportion of FVC, as percentage of predicted [%]	1.148	9	.281	2.819

Table 4.8: One sample / dependent *t* test on female participants spirometric variables' percentage of predicted values ($n = 5$).

Spirometric variable	Test Value = 100			
	t	*df*	Sig. (2-tailed)	Mean Diff.
Peak expiratory flow as percentage of predicted [%]	-3.307	4	.030	-32.465
Forced vital capacity as percentage of predicted [%]	-3.488	4	.025	-11.806
Forced expiratory volume in one second as percentage of predicted [%]	-3.185	4	.033	-20.988
Forced expiratory volume in 1 second as a proportion of FVC, as percentage of predicted [%]	-1.280	4	.270	-5.030

4.4. Treadmill Running Tests Data

Fourteen participants (10 male and 4 female athletes) successfully completed treadmill run and the accompanying respiratory tests. One female athlete did not adjust well to running on treadmill despite undergoing a familiarisation session. Twelve participants completed arterial blood gas (ABG) tests in addition to the aforementioned, with the remaining two runners' cannulisation being unsuccessful due to radial artery spasms. At the time of termination of the incremental exercise, the subjects reached maximum speed of 18.7 ± 1.34 km/hr and 15.5 ± 1.91 km/hr (Mean ± SD), for male and female athletes respectively. Peak speed recorded was 21 km/hr

and 17 km/hr for male and female athletes respectively. The last five stages leading to maximal / termination of exercise were considered in the analyses of exercise respiratory and arterial blood gas data. Average speed for these five exercise stages leading to termination of exercise were 14.72±1.35, 15.60±1.51, 16.70±1.34, 17.70±1.34, 18.70±1.34 and 11.50±1.91, 12.50±1.91, 13.50±1.91, 14.50±1.91, 15.50±1.91for male (*n*=10), and female (*n*=4) participants (Mean±SD) [km/h] respectively. The athletes spent three minutes for each exercise stage before the speed being increased by 1 km/hr, until voluntary termination of the exercise. Several authors (Jones, 1998) have used measures related to speed such as using VO_2 at the speed of 16 and 14 km/hr to judge running economy of male and female endurance athletes respectively.

4.5. Respiratory Data

Exercise respiratory values were taken from fourteen subjects (10 male and 4 female athletes) who completed the tests successfully. Respiratory variables assessed were Tidal Volume (Vt), Breathing Frequency (Fb), Minute Ventilation (VE), Oxygen Consumption (VO_2), Carbon dioxide production VCO_2, and Respiratory Exchange Ratio (RER). The data was subjected to descriptive, one sample *t* test, repeated/paired *t* test, repeated measures ANOVA, as well as Pearson's correlation analyses. The results for these analyses are presented in the following subsections:

4.5.1. Descriptive Analyses of Respiratory Values

The values of the respiratory variables recorded at rest and during treadmill incremental exercise tests are summarized in tables 4.9 to 4.13. These present values recorded at rest, sub-maximal (at about 90-95% of predicted MHR) and maximal (at

termination of the exercise) levels, as well as peak (highest recorded during the test) values, for all the participants and for each gender.

Table 4.9: Respiratory values for athletes at rest, at sub-maximal exercise, maximal exercise, and peak values recorded (Mean ± SD), (n = 14).

Respiratory Variable	At Rest	At sub-maximal exercise	At maximal exercise	Peak
Tidal Volume (Vt) [L/br]	.50±.15	1.70±.35	1.73±.34	1.76±.35
Breathing Frequency (Fb) [br/min]	21.39±3.94	57.30±10.77	58.60±9.99	59.93±10.28
Minute Ventilation (VE) [L/min]	7.80±2.00	71.94±15.58	75.33±16.59	76.41±15.71
Oxygen Consumption (VO_2) [L/min]	.26±.08	3.08±.58	3.11±.62	3.17±.59
Carbon dioxide prodn. VCO_2 [L/min]	.22±.07	3.09±.65	3.18±.67	3.23±.66
Respiratory Exchange Ratio (RER)	.86±.07	1.00±.07	1.02±.07	1.02±.07
Relative VO_2 (rVO_2) [ml/kg/min]	4.89±1.33	58.35±7.48	59.06±9.07	60.20±8.10

Table 4.10: Resting values for respiratory variables (Mean ± SD) summarized by gender and combined/total; male (n = 10), female (n = 4), total (n = 14).

	Gender		
Respiratory Variable	Male	Female	Total
Resting tidal volume [L]	.55±.14	.38±.11	.50±.15
Resting breathing frequency [br/min]	21.64±4.40	20.78±2.94	21.39±3.94
Resting minute ventilation [L]	8.57±1.61	5.88±1.64	7.80±2.00
Resting volume of oxygen consumption [L/min]	.29±.07	.18±.07	.26±.08
Resting volume of carbon dioxide produced [L/min]	.25±.06	.15±.05	.22±.07
Resting respiratory exchange ratio	.86±.08	.84±.04	.86±.066
Rate of oxygen consumption (relative to body weight) at rest [ml/kg/min]	5.30±1.10	3.84±1.41	4.89±1.33

The resting values are comparable with values cited by several authors. According to Elert (2001), the average values for Vt is 500 mL for male and 390 mL for female. Mackenzie (2004) cites values of 600 and 500 mL for (Caucasians) male and female respectively. The author says that for a given standing height, thoraxes of people of

African origin are shorter than of Caucasians of similar age, sex and height, and therefore have lower lung capacity.

Table 4.11: Sub-maximal values for respiratory variables (Mean ± SD) summarized by gender and combined/total; male (n = 10), female (n = 4), total (n = 14).

	Gender		
Respiratory variable	Male	Female	Total
Tidal volume (average) at exercise stage 4 [L]	1.84±.31	1.35±.12	1.70±.35
Breathing frequency (average) at exercise stage 4 [br/min]	59.28±12.27	52.35±2.26	57.30±10.77
Minute ventilation (average) at exercise stage 4 [L/min]	79.45±10.90	53.19±6.22	71.94±15.58
Rate of oxygen consumption (absolute) at exercise stage 4 [L/min]	3.40±.29	2.29±.12	3.08±.58
Rate of carbondioxide production at exercise stage 4 [L/min]	3.41±.44	2.28±.20	3.09±.65
Respiratory exchange ratio at exercise stage 4	1.00±.07	1.00±.07	1.00±.07
Subject's rate of oxygen consumption (relative to body weight) at exercise stage 4 [ml/kg/min]	62.32±4.13	48.42±2.66	58.35±7.48

Table 4.12: Maximal values for respiratory variables (Mean ± SD) summarized by gender and combined/total; male (n = 10), female (n = 4), total (n = 14).

	Gender		
Respiratory variable	Male	Female	Total
Tidal volume (average) at exercise stage 5 [L]	1.87±.29	1.39±.13	1.73±.34
Breathing frequency (average) at exercise stage 5 [br/min]	60.51±10.88	53.83±5.94	58.60±10.00
Minute ventilation (average) at exercise stage 5 [L/min]	83.07±11.98	56.00±7.97	75.33±16.59
Rate of oxygen consumption (absolute) at exercise stage 5 [L/min]	3.44±.35	2.30±.18	3.11±.62
Rate of carbondioxide production at exercise stage 5 [L/min]	3.51±.46	2.37±.27	3.18±.67
Respiratory exchange ratio at exercise stage 5	1.02±.07	1.03±.08	1.02±.07
Subject's rate of oxygen consumption (relative to body weight) at exercise stage 5 [ml/kg/min]	63.22±6.76	48.66±4.26	59.06±9.08

The variables values are known to increase with exercise intensity at varying rates, with sub-maximal and maximal values used to estimate fitness and metabolic statuses of the individual (Carely, *et al.,* 2005; Haff & Dumke, 2012; Plowman & Smith, 1997).

Table 4.13: Peak values for respiratory variables (Mean ± SD) summarized by gender and combined/total; male (*n* = 10), female (*n* = 4), total (*n* = 14).

Respiratory variable	Gender		Total
	Male	Female	
Highest tidal volume during exercise [L]	1.90±.29	1.40±.12	1.76±.34
Highest breathing frequency during exercise [br/min]	61.77±11.37	55.34±5.53	59.93±10.28
Highest minute ventilation during exercise [L/min]	84.24±10.14	56.84±6.78	76.41±15.71
Peak oxygen consumption (absolute) [L/min]	3.50±.26	2.35±.16	3.17±.59
Highest rate of carbon dioxide production during exercise [L/min]	3.57±.41	2.38±.27	3.23±.66
Highest respiratory exchange ratio during exercise	1.02±.07	1.03±.07	1.02±.07
Highest rate of oxygen consumption (relative to body weight) during exercise [ml/kg/min]	64.36±4.88	49.82±3.45	60.20±8.10

Peak values can be differentiated from maximal values in that the latter are the values recorded at the termination of exercise with or without a plateau, while the former are the highest recorded values during the exercise test duration. Robergs (2001) observes that the term VO_2 max should not be applied to the peak VO_2 attained without a VO_2 plateau. This can apply to the other tested variables. It is notable that some variable values may have reached the peak before the terminal stage of the exercise and then tended to plateau, or even decreased towards the end of the test.

4.5.2. Repeated Measures Analyses and Interpretation of Respiratory Values

Repeated measures / paired *t* test was performed for the different respiratory variables to compare sub-maximal and maximal values. The *t* statistic and the corresponding *p* values for each of the respiratory parameter are shown in tables 4.14 to 4.16.

Table 4.14: Paired sample / repeated measures *t* test comparing sub-maximal and maximal respiratory values ($n = 14$).

Paired variables		Paired Differences			*t*	*df*	Sig.(2-tailed)
		Mean	Std. Dev.	SE Mean			
Pair 1	Tidal volume (average) at exercise stage 4 [L] - Tidal volume (average) at exercise stage 5 [L]	-.0308	.0767	.0205	-1.504	13	.157
Pair 2	Breathing frequency (average) at exercise stage 4 [br/min] - Breathing frequency (average) at exercise stage 5 [br/min]	-1.305	3.520	.9406	-1.387	13	.189
Pair 3	Minute ventilation (average) at exercise stage 4 [L/min] - Minute ventilation (average) at exercise stage 5 [L/min]	-3.389	5.636	1.506	-2.250	13	.042
Pair 4	Rate of oxygen consumption (absolute/measured) at exercise stage 4 [L/min] - Rate of oxygen consumption (absolute/measured) at exercise stage 5 [L/min]	-.0337	.1699	.0454	-.743	13	.471
Pair 5	Rate of carbondioxide production at exercise stage 4 [L/min] - Rate of carbondioxide production at exercise stage 5 [L/min]	-.0940	.1993	.0533	-1.765	13	.101
Pair 6	Respiratory exchange ratio at exercise stage 4 - Respiratory exchange ratio at exercise stage 5	-.0214	.0176	.0047	-4.553	13	.001
Pair 7	Rate of oxygen consumption (relative to body weight) at exercise stage 4 [ml/kg/min] - Rate of oxygen consumption (relative to body weight) at exercise stage 5 [ml/kg/min]	-.7097	3.240	.8661	-.819	13	.427

Significant difference between a given variable's sub-maximal and maximal values may indicate that the variable is a critical limiting factor for endurance performance among Kenyan runners. This is particularly the case if the maximal value of this same variable is not significant from peak value. VE and RER maximal values are significantly different from the variables' sub-maximal values (Table 4.14). The maximal values for these variables are not significantly different from peak values (Table 4.15).

Table 4.15: Repeated measures *t* test comparing maximal and peak (highest recorded) respiratory values ($n = 14$).

Paired variables		Paired Differences			*t*	*df*	Sig.(2-tailed)
		Mean	Std. Dev.	SE Mean			
Pair 1	Highest tidal volume during exercise [L] - Tidal volume (average) at exercise stage 5 [L]	.0254	.0485	.0130	1.961	13	.072
Pair 2	Highest breathing frequency during exercise [br/min] - Breathing frequency (average) at exercise stage 5 [br/min]	1.332	1.689	.4514	2.950	13	.011
Pair 3	Highest minute ventilation during exercise [L/min] - Minute ventilation (average) at exercise stage 5 [L/min]	1.081	3.207	.8571	1.261	13	.229
Pair 4	Peak oxygen consumption (absolute/measured) [L/min] - Rate of oxygen consumption (absolute/measured) at exercise stage 5 [L/min]	.0608	.1325	.0354	1.718	13	.110
Pair 5	Highest rate of carbondioxide production during exercise [L/min] - Rate of carbondioxide production at exercise stage 5 [L/min]	.0438	.1264	.0338	1.295	13	.218
Pair 6	Highest respiratory exchange ratio during exercise - Respiratory exchange ratio at exercise stage 5	.0017	.0037	.0010	1.704	13	.112
Pair 7	Highest rate of oxygen consumption (relative to body weight) during exercise [ml/kg/min] - Rate of oxygen consumption (relative to body weight) at exercise stage 5 [ml/kg/min]	1.142	2.449	.6545	1.744	13	.105

Significant difference between a given variable's maximal and peak values may indicate that the variable may have been affected at (or reduced prior to) maximal level after reaching peak at sub-maximal stage. It can also indicate that there is reserve potential which can be utilized, and there is greater tolerance of any adverse effects associated with this variable. Only breathing frequency recorded significant difference between maximal and peak values (Table 4.15). This may have been affected when the striding rhythm in higher running intensity (towards maximal stage) got unsynchronized with breathing patterns.

Table 4.16: Repeated measures *t* test comparing sub-maximal and peak (highest recorded) respiratory values (*n* = 14).

Paired variables		Paired Differences			*t*	*df*	Sig.(2-tailed)
		Mean	Std. Dev.	SE Mean			
Pair 1	Highest tidal volume during exercise [L] - Tidal volume (average) at exercise stage 4 [L]	.0563	.0513	.0137	4.099	13	.001
Pair 2	Highest breathing frequency during exercise [br/min] - Breathing frequency (average) at exercise stage 4 [br/min]	2.637	2.595	.6935	3.802	13	.002
Pair 3	Highest minute ventilation during exercise [L/min] - Minute ventilation (average) at exercise stage 4 [L/min]	4.470	3.327	.8891	5.027	13	.000
Pair 4	Peak oxygen consumption (absolute/measured) [L/min] - Rate of oxygen consumption (absolute/measured) at exercise stage 4 [L/min]	.0945	.0797	.0213	4.439	13	.001
Pair 5	Highest rate of carbondioxide production during exercise [L/min] - Rate of carbondioxide production at exercise stage 4 [L/min]	.1378	.1051	.0281	4.907	13	.000
Pair 6	Highest respiratory exchange ratio during exercise - Respiratory exchange ratio at exercise stage 4	.0231	.0156	.0042	5.549	13	.000
Pair 7	Highest rate of oxygen consumption (relative to body weight) during exercise [ml/kg/min] - Rate of oxygen consumption (relative to body weight) at exercise stage 4 [ml/kg/min]	1.851	1.614	.4314	4.291	13	.001

Illustrations of trends for the variables that registered significant difference between sub-maximal and maximal values (VE, RER) or between maximal and peak values (Fb), are presented in figures 4.1 to 4.3. Repeated measures ANOVA analyses compared sub-maximal, peak (highest recorded) and maximal (recorded at the end of exercise) values. The *F* statistic values and the corresponding *p* values for the exercise respiratory parameters are shown in tables 4.17 to 4.21.

4.5.2.1. Minute Ventilation (VE)

Minute Ventilation (VE) variable is normally expected to increase proportionally with increasing exercise intensity up to about 60% of maximum effort, then more sharply (after ventilation threshold) (Haff & Dumke, 2012). Values of 145.7±27.5 L/min have been reported at maximal endurance treadmill tests (Carey, Pliego & Raymond, 2008) and 162.0±6.4 L/min during competition (Kippelen *et al.,* 2005). Peak values recorded during the current study are lower; 84.24±10.14 (male), 56.84±6.78 (female) [L/min] (Table 13, Figure 4.1). McArdle, Katch and Katch (2010) observe that during strenuous exercise, elite endurance athletes may increase exercise minute ventilation to 100 L or more (about 17 to 20 times the resting value). But it is expected that persons with superior gaseous exchange capacity will need relatively less VE at rest and during a given exercise intensity (Hallstrand, Bates & Schoene, 2000).

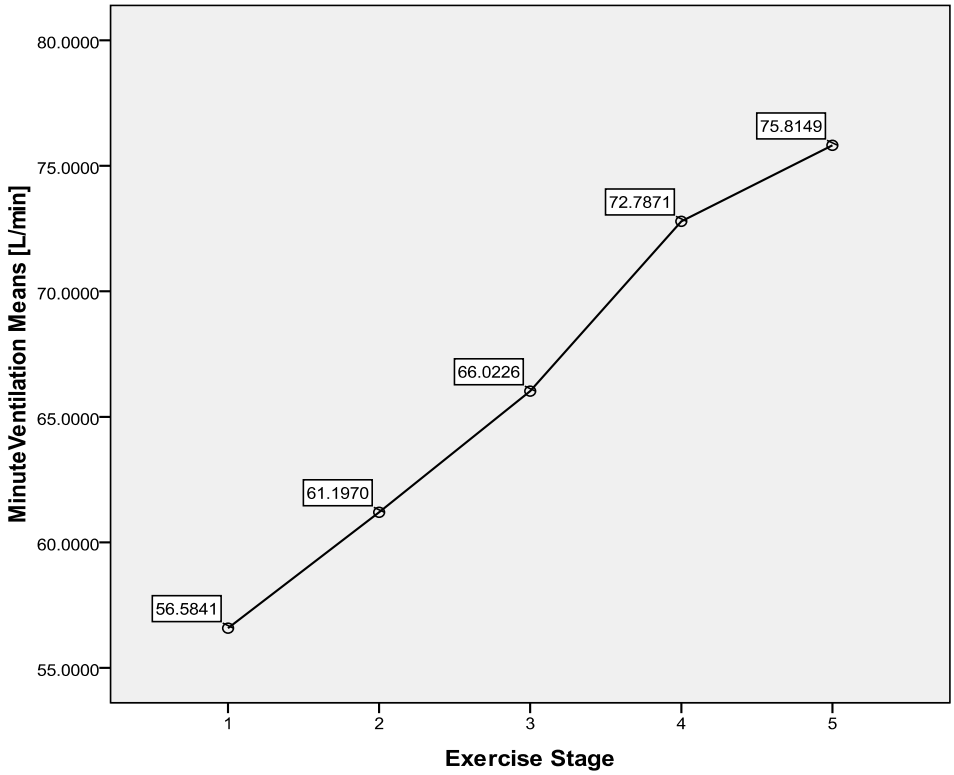

Figure 4.1: Minute ventilation (VE) means for five exercise stages leading to maximal endurance treadmill run (n =14).

Table 4.17a: Repeated measures ANOVA test comparing minute ventilation (VE) for three exercise stages leading to maximal endurance treadmill run (*n* =14).

		Sum of Squares	*df*	Mean Square	F	Sig
Between People		9843.256	13	757.174		
Within People	Between Items	806.924	2	403.462	19.854	.000
	Residual	528.368	26	20.322		
	Total	1335.292	28	47.689		
Total		11178.548	41	272.648		

Grand Mean = 70.697712 Within-subject effects is significant at the .01 level

Table 4.17b: Pairwise comparison of minute ventilation (VE) for three exercise stages leading to maximal endurance treadmill run (*n* =14).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
3	4	-7.129*	1.206	.000	-9.734	-4.523
	5	-10.517*	2.233	.000	-15.341	-5.693
4	3	7.129*	1.206	.000	4.523	9.734
	5	-3.389*	1.506	.042	-6.643	-.135
5	3	10.517*	2.233	.000	5.693	15.341
	4	3.389*	1.506	.042	.135	6.643

*. The mean difference is significant at the .05 level.

Table 4.17c: Pairwise comparison of sub-maximal, maximal and peak (highest recorded) (stages 4, 5 and pk values) minute ventilation (VE) values (*n* = 14).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
4	pk	-4.470*	.889	.000	-6.391	-2.549
	5	-3.389*	1.506	.042	-6.643	-.135
pk	4	4.470*	.889	.000	2.549	6.391
	5	1.081	.857	.229	-.771	2.933
5	4	3.389*	1.506	.042	.135	6.643
	pk	-1.081	.857	.229	-2.933	.771

*. The mean difference is significant at the .05 level.

Minute ventilation maximal values (recorded during the maximal stage of the test) are significantly different from sub-maximal values, and do not differ significantly from peak (highest recorded during the test) values. This indicates that VE (or variable/s associated with it) is a critical limiting factor to endurance performance in the Kenyan runners.

4.5.2.2. Breathing Frequency (Fb)

The breathing frequency (Fb) variable is normally expected to increase with increasing exercise intensity. Together with increased tidal volume, the variables account for the increased VE. Synchronisation of breathing action with running rhythm is important at high intensity endurance exercise for efficiency (Harriman, 2011), while Fb and VE have been shown to significantly correlate to VO_2 max (Carey *et al.,* 2008).

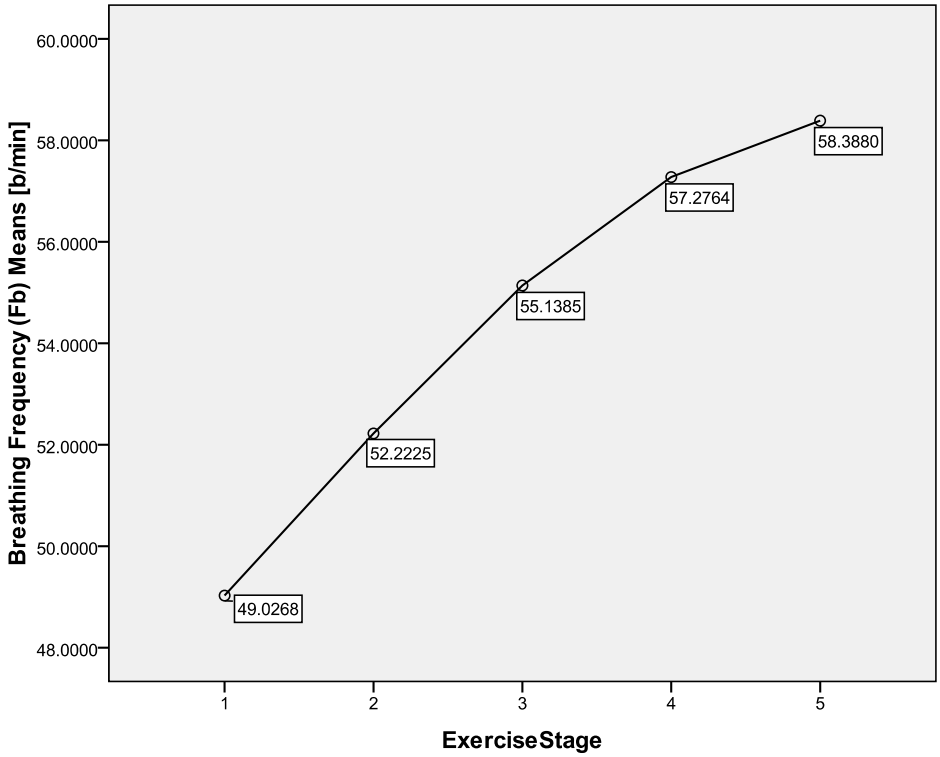

Figure 4.2: Breathing frequency (Fb) means for five exercise stages leading to maximal endurance treadmill run (n =14).

Values of 48.3±5.7 breaths per min have been reported for endurance runners during treadmill tests and 51.7±6.7 during cycle ergometry (Carey *et al.,* 2008). McArdle *et al.* (2010) observe that during strenuous exercise, elite endurance athletes breathe as rapidly as 60 to 70 times each minute during maximal exercise. With tidal volume of 2.0 L and above occurring during exercise, such increases in Fb and Vt may increase exercise minute ventilation to 100 L or more (about 17 to 20 times the resting value). Values recorded during maximal exercise in the current study indicates similar trend (see Figure 4.2) and therefore typical, with Fb and VE registering significant association with VO_2 at maximal exercise stage (see Table 4.22).

Table 4.18a: Repeated measures ANOVA test comparing breathing frequency (Fb) for three exercise stages leading to maximal endurance treadmill run (*n* =14).

		Sum of Squares	*df*	Mean Square	*F*	Sig
Between People		4091.167	13	314.705		
Within People	Between Items	79.996	2	39.998	5.191	.013
	Residual	200.323	26	7.705		
	Total	280.319	28	10.011		
Total		4371.486	41	106.622		

Grand Mean = 57.048917 Within-subject effects is significant at the .05 level

Table 4.18b: Pairwise comparison of breathing frequency (Fb) for three exercise stages leading to maximal endurance treadmill run (*n* =14).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
3	4	-2.048*	.869	.035	-3.925	-.172
	5	-3.353*	1.289	.022	-6.139	-.568
4	3	2.048*	.869	.035	.172	3.925
	5	-1.305	.941	.189	-3.337	.727
5	3	3.353*	1.289	.022	.568	6.139
	4	1.305	.941	.189	-.727	3.337

*. The mean difference is significant at the .05 level.

Breathing frequency recorded significant difference between maximal and peak values (Table 4.18c) and no significant difference between sub-maximal and maximal values (Table 4.18b and c). The high pace of running at maximal stage may have reached a rhythm beyond that which breathing action can keep up with.

Table 4.18c: Pairwise comparison of sub-maximal, maximal and peak (highest recorded) (stages 4, 5 and pk values) breathing frequency (Fb) values (n = 14).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
4	pk	-2.637*	.694	.002	-4.135	-1.138
	5	-1.305	.941	.189	-3.337	.727
pk	4	2.637*	.694	.002	1.138	4.135
	5	1.332*	.451	.011	.357	2.307
5	4	1.305	.941	.189	-.727	3.337
	pk	-1.332*	.451	.011	-2.307	-.357

*. The mean difference is significant at the .05 level.

4.5.2.3. Respiratory Exchange Ratio (RER)

The respiratory exchange ratio (RER) is normally expected to increase with increasing exercise intensity. Values of over 1.2 have been reported in maximal endurance exercise, with values higher than 1.0 used as criterion for accepting test trial as maximal (Haff & Dumke, 2012). Values recorded during the current study indicate that the participants exerted themselves to reach maximal effort at the termination of the exercise (see Figure 4.3). RER maximal values (recorded during the maximal stage of the test) are significantly different from sub-maximal values (Table 4.19b), and do not differ significantly from peak (highest recorded during the test) values (Table 4.19c). This indicates that RER (or variable/s associated with it) is a critical limiting factor to endurance performance in the runners.

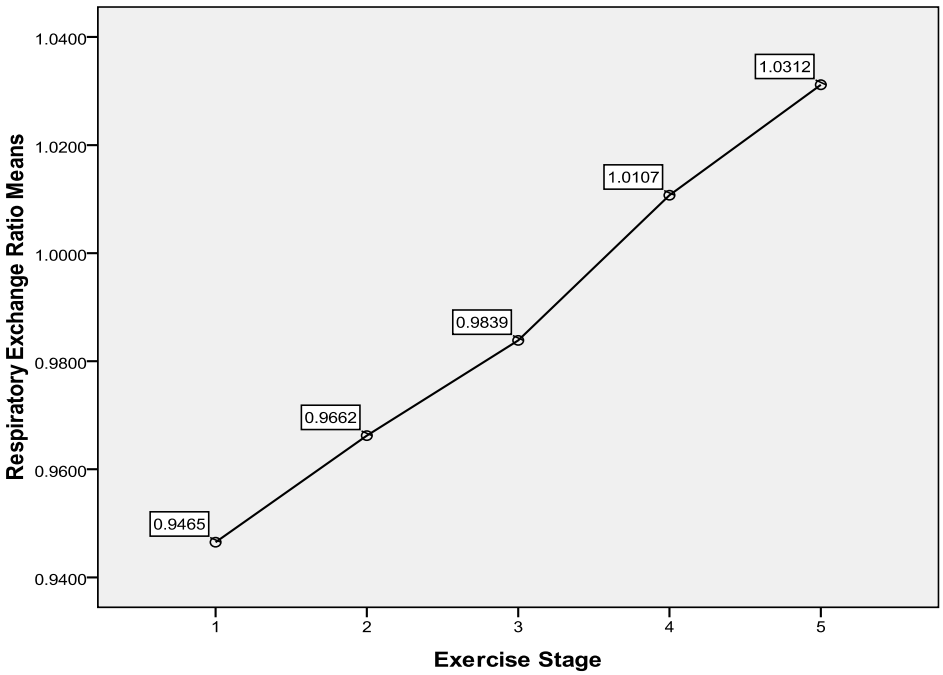

Figure 4.3: Respiratory exchange ratio means for five exercise stages leading to maximal endurance treadmill run (*n* =14).

Table 4.19a: Repeated measures ANOVA test comparing respiratory exchange ratio (RER) for three exercise stages leading to maximal endurance treadmill run (*n* =14).

		Sum of Squares	*df*	Mean Square	*F*	Sig
Between People		.175	13	.013		
Within People	Between Items	.017	2	.009	27.145	.000
	Residual	.008	26	.000		
	Total	.026	28	.001		
Total		.200	41	.005		

Grand Mean = .999667 Within-subject effects is significant at the .01 level

Table 4.19b: Pairwise comparison of respiratory exchange ratio for three exercise stages leading to maximal endurance treadmill run (*n* =14).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
3	4	-.028*	.006	.000	-.040	-.016
	5	-.049*	.009	.000	-.069	-.030
4	3	.028*	.006	.000	.016	.040
	5	-.021*	.005	.001	-.032	-.011
5	3	.049*	.009	.000	.030	.069
	4	.021*	.005	.001	.011	.032

*. The mean difference is significant at the .05 level.

Table 4.19c: Pairwise comparison of sub-maximal, maximal and peak (highest recorded) (stages 4, 5 and pk values) respiratory exchange ratio values (n = 14).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
4	pk	-.023*	.004	.000	-.032	-.014
	5	-.021*	.005	.001	-.032	-.011
pk	4	.023*	.004	.000	.014	.032
	5	.002	.001	.112	.000	.004
5	4	.021*	.005	.001	.011	.032
	pk	-.002	.001	.112	-.004	.000

*. The mean difference is significant at the .05 level.

4.5.2.4. Status of Oxygen Consumption (VO_2)

Absolute oxygen consumption rate (VO_2) peak values for males (3.50±.26) and females (2.26±.26) [L/min] were significantly higher than predicted values (p = .001) (see Table 4.20), for people of similar age and height in general population.

Table 4.20: Paired t test analyses on subject's peak oxygen consumption (absolute/measured) values versus predicted values (Mean ± SD) (n = 14).

Paired variables		Paired Differences			t	df	Sig. (2-tailed)
		Mean	Std. Dev.	Std. Err.			
Pair 1	Subject's peak oxygen consumption (absolute/measured) [L/min] - Subject's predicted peak oxygen consumption (absolute/measured) [L/min]	.3883	.2828	.0756	5.137	13	.000
Pair 2	Rate of oxygen consumption (absolute/measured) at exercise stage 5 [L/min] - Subject's predicted peak oxygen consumption (absolute/measured) [L/min]	.3275	.3623	.0968	3.382	13	.005
Pair 3	Rate of oxygen consumption (absolute/measured) at exercise stage 4 [L/min] - Subject's predicted peak oxygen consumption (absolute) [L/min]	.2937	.2479	.0662	4.434	13	.001

Oxygen consumption rate relative to body weight (rVO_2 max) for males (64.4±4.9) and females (50.0±1.9) [ml/kg/min] rated superior and excellent (Figure 4.4), judged on cardio-respiratory fitness classification from the Physical Fitness Specialist Manual as presented in Heyward, (2006) (see Appendix III).

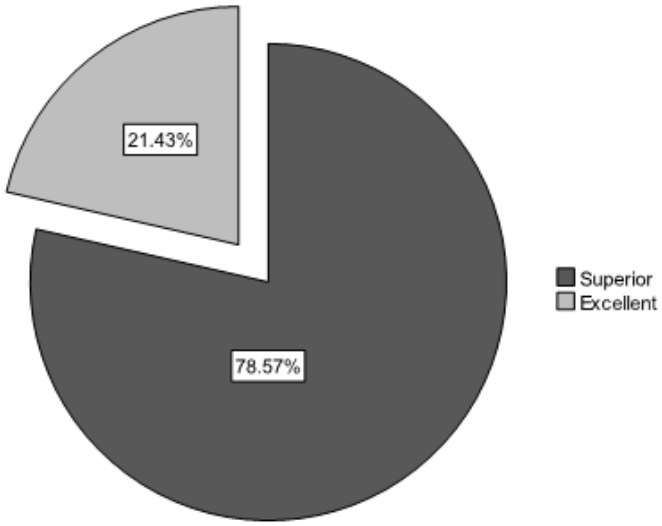

Figure 4.4: Status of subject's highest rate of oxygen consumption during exercise (*n*=14), as per Cooper's Fitness classification (Heyward, 2006).

Figures 4.5 a-c illustrates rVO_2 trend for the five exercise stages leading to maximal endurance treadmill run. There was high sub-maximal rVO_2 (at exercise stage 4) which was not significantly different from maximal (at exercise stage 5) values (see Table 4.21b). Onset of plateau can be observed on the mean relative oxygen consumption towards the termination of incremental endurance exercise (figures 4.5 a-c). Discussion on whether athletes experience plateau during tests of this nature in this variable have been ongoing (Robergs, 2001). The results of the current study seem to support existence of this occurrence among endurance athletes.

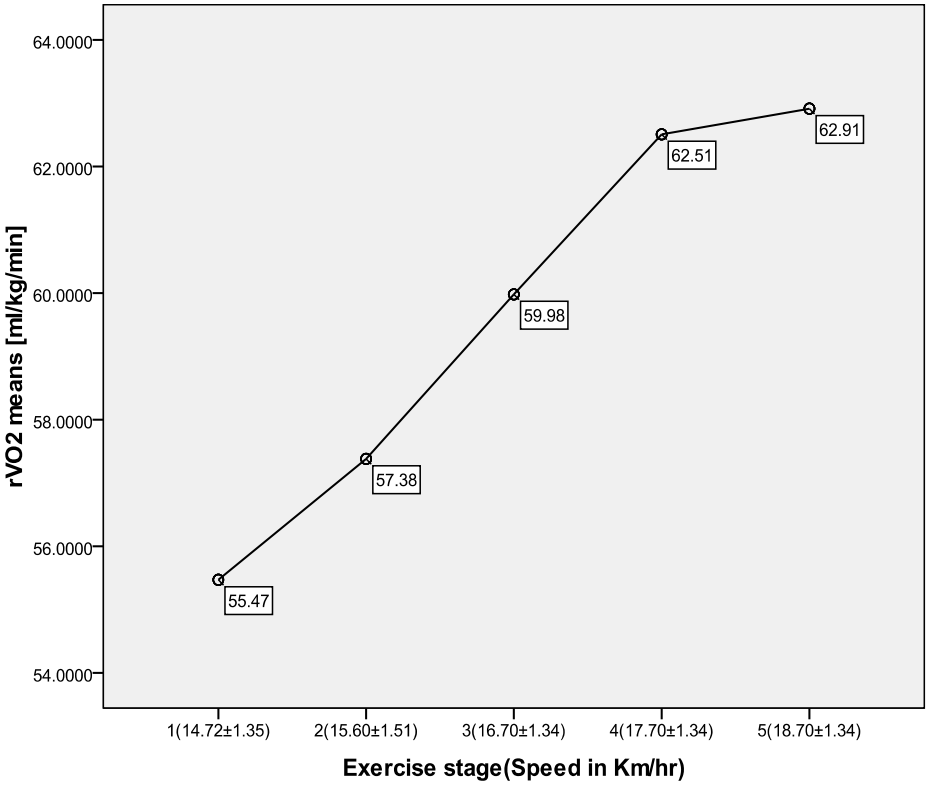

Figure 4.5a: Relative oxygen consumption rate (rVO_2) means for five exercise stages leading to maximal endurance treadmill run for male athletes (n =10).

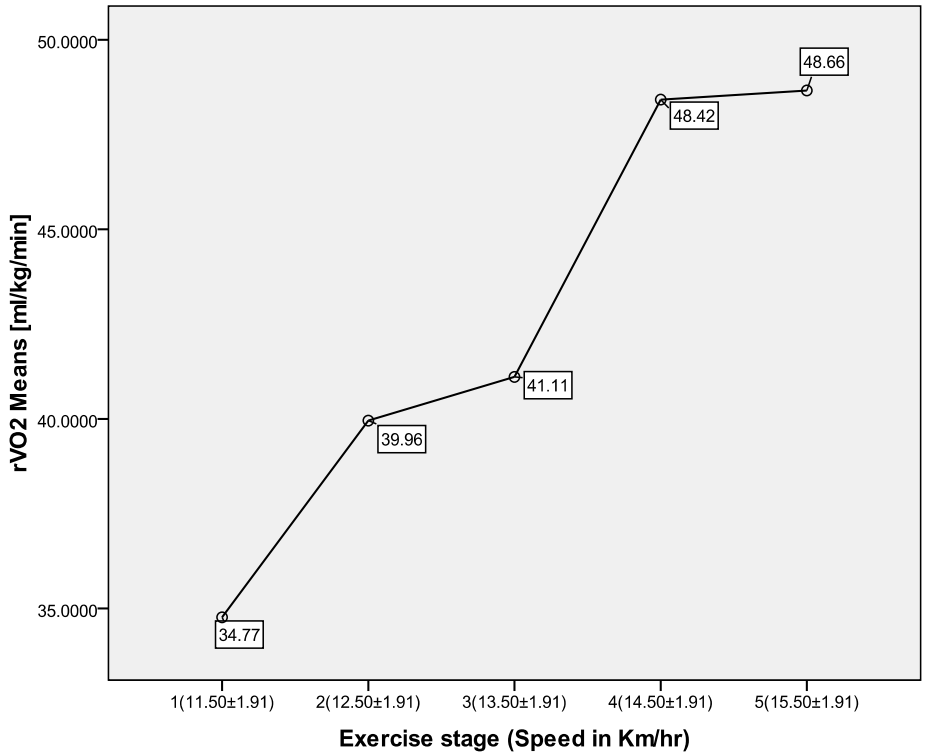

Figure 4.5b: Relative oxygen consumption rate (rVO_2) means for five exercise stages leading to maximal endurance treadmill run for female athletes (n =4).

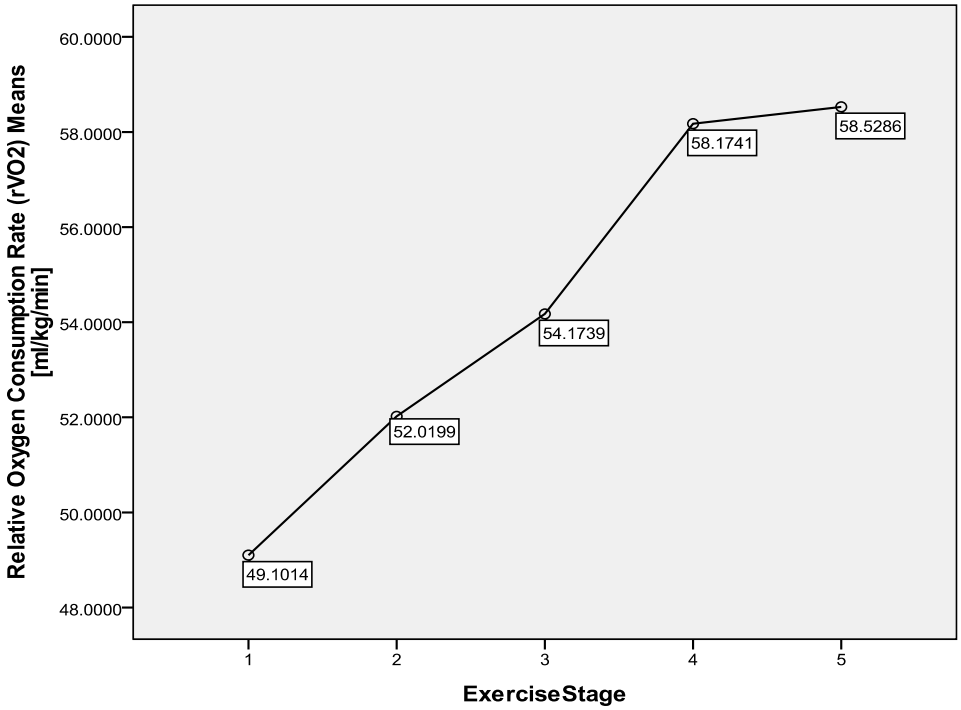

Figure 4.5c: Relative oxygen consumption rate (rVO_2) means for five exercise stages leading to maximal endurance treadmill run (n =14).

Table 4.21a: Repeated measures ANOVA test comparing rVO_2 for three exercise stages leading to maximal endurance treadmill run (n =14).

		Sum of Squares	*df*	Mean Square	*F*	Sig
Between People		2738.600	13	210.662		
Within People	Between Items	210.194	2	105.097	10.878	.000
	Residual	251.187	26	9.661		
	Total	461.381	28	16.478		
Total		3199.980	41	78.048		

Grand Mean = 57.137511 Within-subject effects is significant at the .01 level

Table 4.21b: Pairwise comparison of relative oxygen consumption rate (rVO_2) for three exercise stages leading to maximal endurance treadmill run (n =14).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
3	4	-4.351*	1.007	.001	-6.527	-2.174
	5	-5.060*	1.541	.006	-8.390	-1.731
4	3	4.351*	1.007	.001	2.174	6.527
	5	-.710	.866	.427	-2.581	1.161
5	3	5.060*	1.541	.006	1.731	8.390
	4	.710	.866	.427	-1.161	2.581

*. The mean difference is significant at the .05 level.

Table 4.21c: Pairwise comparison of sub-maximal, maximal and peak (highest recorded) relative oxygen consumption rate (rVO_2) values (n = 14).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
4	pk	-1.851*	.431	.001	-2.784	-.919
	5	-.710	.866	.427	-2.581	1.161
pk	4	1.851*	.431	.001	.919	2.784
	5	1.142	.655	.105	-.272	2.556
5	4	.710	.866	.427	-1.161	2.581
	pk	-1.142	.655	.105	-2.556	.272

*. The mean difference is significant at the .05 level.

4.5.3. Correlation Analyses for Respiratory and Spirometric Values

Correlating respiratory and spirometric variables with performance indices such as rVO_2 and speed / velocity at sub-maximal and maximal stage showed significant association for some variables. Pearson Correlation coefficient and their level of significance are presented in tables 4.22 below.

Table 4.22: Correlation between rVO_2 and spirometric & exercise variables, at exercise sub-maximal level (a) and at maximal level (b).

Variable	**a) Sub-maximal stage**		**b) Maximal stage**	
	Pearson Correlation	**Sig. (2-tailed)**	**Pearson Correlation**	**Sig. (2-tailed)**
PIF	.366	.198	.318	.268
PEF	.625	.017*	.447	.109
FVC	.741	.002**	.608	.021*
FEV_1	.658	.010*	.520	.056
FEV_1/FVC	.182	.533	.083	.778
MIP	-.038	.897	.054	.855
Vt	.518	.058	.460	.098
Fb	.450	.106	.535	.049*
VE	.792	.001**	.762	.002**
RER	-.191	.513	-.350	.220
%MHR	.241	.429	.420	.154
Speed/Velocity	.670	.009**	.515	.060

* Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

Forced vital capacity (FVC) and minute ventilation (VE) had significant correlation with relative oxygen consumption (rVO_2) both at sub-maximal and maximal levels. Peak expiratory flow (PEF), forced expiratory volume in one second (FEV_1), FVC, VE and speed / velocity had higher correlation with rVO_2 at sub-maximal than at maximal levels. Breathing frequency (Fb) had significant correlation with rVO_2 at maximal level but no significant correlation at sub-maximal level.

4.5.4. Multiple Regression Analyses for Respiratory and Spirometric Values

Regression analysis for FVC and VE (variables which showed significant correlation with performance indices) produced the following values for sub-maximal rVO_2 (a) and sub-maximal speed (b):

a) Dependent Variable: Subject's rate of oxygen consumption (relative to body weight) (rVO_2) at exercise stage 4 [ml/kg/min]

Adjusted R square = .596; $F_{1,12} = 20.200$, $p < 0.005$ (using the stepwise method).
Significant variable are shown below.

Predictor Variable	**Beta**	***p***
Minute ventilation (VE) [L/min]:	.792	$p < 0.001$

(Forced vital capacity [L] was not a significant predictor in this model)

b) Dependent Variable: Velocity/Speed at sub-maximal level [km/h]

Adjusted R square = .405; $F_{1,12} = 9.862$, $p < 0.05$ (using the stepwise method).
Significant variable are shown below.

Predictor Variable	**Beta**	***p***
Minute ventilation (VE) [L/min]:	.672	$p < 0.05$

(Forced vital capacity [L] was not a significant predictor in this model)

The results show that only VE is a significant predictor for sub-maximal performance indicators, but a better predictor of sub-maximal rVO_2 than sub-maximal speed. However this analysis was used with caution as it only met the absolute minimum of multiple regression requirement of having five times as many participants as predictor variables in the model. This is due to the relatively low number of observations associated with the nature of research design used in the current study.

4.6. Arterial Blood Gas Data

Arterial blood gas (ABG) values were taken from twelve participants (9 male and 3 female athletes) who completed the tests successfully. The data was subjected to descriptive, repeated/paired *t* test, repeated measures ANOVA, as well as correlation analyses. The results for these analyses are presented in the following subsections.

4.6.1. Descriptive Analyses for Arterial Blood Gas Values

The Arterial Blood Gas values recorded at rest and during treadmill incremental exercise tests are summarized for the resting, sub-maximal, maximal and extreme recorded values, as well as for male and female subjects (see tables 4.23 - 4.27).

Table 4.23: Arterial blood gas values for athletes at rest, sub-maximal exercise, maximal exercise, and extreme values recorded during exercise (Mean±SD), (n = 12).

ABG Variable	At Rest	At sub-maximal exercise	At maximal exercise	Extreme (Peak or Lowest) recorded
Partial pressure of arterial oxygen (PaO_2) [mmHg]	79.92±6.26	67.06±4.05	65.59±4.26	63.69± 4.28 (Lowest)
Partial pressure of arterial carbon dioxide ($PaCO_2$) [mmHg]	34.08±2.64	34.19±4.77	34.15±3.44	36.13± 3.82 (Peak)
Arterial oxygen saturation (SaO_2) [%]	96.58±.96	91.53±3.88	90.16±4.22	89.94± 4.13 (Lowest)
Normalized arterial oxygen saturation(SaO_2npHTC)[%]	95.58±1.06	92.74±1.27	92.26±1.47	91.67± 1.43 (Lowest)
Blood acid-base level (pH)	7.41±.04	7.33±.07	7.31±.08	7.30±.08 (Lowest)
Partial pressure of alveolar oxygen (PAO_2) [mmHg]	84.51±4.28	88.14±5.04	88.73±3.57	89.65± 3.81 (Peak)
Alveolar to arterial oxygen partial pressure difference (A-aDO_2) [mmHg]	4.58±3.47	21.08±5.78	23.14±6.56	23.39± 6.39 (Peak)
Blood bicarbonate (HCO_3) [mmol/L]	22.76±1.48	18.91±2.96	17.80±3.03	17.79± 3.01 (Lowest)
Total blood hemoglobin (tHb) [g/dL]	14.50±1.29	15.13±1.27	15.33±1.43	15.47± 1.38 (Peak)

According to several authors (Jindal *et al.,* 2008; West, 2008; Woodruff, 2009), normal reference ranges for ABG values at rest are as follows; pH; 7.35 to 7.45, $PaCO_2$; 35 to 45 mmHg, HCO_3; 22 to 26mEq/L, PaO_2; 80 to 100 mmHg, SaO_2; 95 to 100% at sea level. The current study was conducted at a location with barometric pressure of 636 mmHg which is expected to correspond to $PaCO_2$ of 35 mmHg, PaO_2 of 77 mmHg and SaO_2 of 96% (Baillie, 2010). During exercise, these values are expected to change due to increased metabolism associated with higher demands of the various body systems involved.

Table 4.24: Resting values for arterial blood gas variables (Mean ± SD) summarized by gender and combined/total; male (n = 9), female (n = 3), total (n = 12).

ABG Variable	Gender		Total
	Male	Female	
Partial pressure of arterial oxygen when the subject is at rest [mmHg]	78.79±6.91	83.34±1.06	79.92±6.26
Partial pressure of arterial carbon dioxide when the subject is at rest [mmHg]	34.25±2.59	33.57±3.30	34.08±2.64
Arterial oxygen saturation when the subject is at rest [%]	96.48±1.08	96.87±.55	96.58±.96
Normalized arterial oxygen saturation at rest [%]	95.38±1.16	96.19±.14	95.58±1.06
Blood pH (acid-base level) at rest	7.41±.04	7.39±.05	7.41±.04
Partial pressure of alveolar oxygen when the subject is at rest [mmHg]	84.51±4.89	84.49±2.26	84.51±4.28
Alveolar to arterial oxygen partial pressure difference when the subject is at rest [mmHg]	5.73±3.04	1.15±2.41	4.58±3.47
Blood bicarbonate ions at rest [mmol/L]	23.04±1.21	21.93±2.20	22.76±1.48
Total blood hemoglobin at rest [g/dL]	14.87±1.25	13.38±.65	14.50±1.29

Arterial blood gas samples values are evaluated using a step by step method (Jindal *et al.,* 2008; West, 2008; Woodruff, 2009) as follows:

1) Checking whether the pH is out of range

2) Checking whether $PaCO_2$ is normal

3) Checking whether the HCO_3 is out of range

4) Match the abnormal result with the pH

5) Checking whether the $PaCO_2$ or HCO_3 go in the opposite direction of the pH

6) Checking whether the PaO_2 and SaO_2 are out of range

Various conclusions (and decisions) are arrived at depending on the status of ABG for each evaluation step, and in relation to the outcome of the other steps. When pH is out of range, the sample is either acidotic (<7.35) or alkalotic (>7.45). It is said to be normal acidotic when in the range of 7.35 to <7.4, and normal alkalotic when in the range of >7.4 to 7.45. For this study therefore, the average pH value for participants' arterial blood recorded is normal alkalotic at rest (7.41±.04), and acidotic at sub-maximal (7.33±.07), maximal (7.31±.08) and for the extreme / lowest recorded value during exercise (7.30±.08) (see Table 4.23). When values for each gender are considered separately, the only differences were that the female were at normal acidotic range (7.39±.05) compared to male who were normal alkalotic (7.41±.04) at rest, and that the male were at lower acidotic level (7.30±.09) than the female (7.33±.02) at the maximal exercise and lowest values recorded during exercise (7.30±.09[male], 7.31±.01[female]) (see tables 4.24 to 4.27).

The normal $PaCO_2$ at near sea level is 35 to 45 mmHg. When it is out of range, it is either acidotic (>45 mmHg) or alkalotic (<35 mmHg). It is said to be normal acidotic when in the range of >40 to 45 mmHg, and normal alkalotic when in the range of 35 to <40 mmHg (Jindal *et al.,* 2008; West, 2008; Woodruff, 2009). Considering the location of the current study with barometric pressure of 636 mmHg, the normal range of $PaCO_2$ is 30 to 40 mmHg (Baillie, 2010). For this study therefore, the average $PaCO_2$ value for participants' arterial blood recorded is normal alkalotic at rest (34.08±2.64 mmHg), at sub-maximal (34.19±4.77 mmHg) and at maximal

(34.15±3.44 mmHg) (see Table 4.23). When values for each gender are considered separately, the only difference is that female participants were normal acidotic at sub-maximal exercise (35.25±7.53 mmHg) compared to male who were normal alkalotic (33.84±4.07 mmHg) (see Table 4.25).

Table 4.25: Sub-maximal values for arterial blood gas variables (Mean ± SD) summarized by gender and combined/total; male (*n* = 9), female (*n* = 3), total (*n* = 12).

ABG Variable	Gender		Total
	Male	Female	
Partial pressure of arterial oxygen at exercise stage 4 [mmHg]	66.03±4.00	70.15±2.67	67.06±4.05
Partial pressure of arterial carbon dioxide at exercise stage 4 [mmHg]	33.84±4.07	35.25±7.53	34.19±4.77
Arterial oxygen saturation at exercise stage 4 [%]	91.12±4.27	92.73±2.65	91.53±3.88
Nomalised arterial oxygen saturation at exercise stage 4 [%]	92.39±1.25	93.80±.67	92.74±1.27
Blood pH (acid-base level) at exercise stage 4	7.33±.08	7.33±.01	7.33±.07
Partial pressure of alveolar oxygen at exercise stage 4 [mmHg]	88.52±3.97	87.01±8.62	88.14±5.04
Alveolar to arterial oxygen partial pressure difference at exercise stage 4 [mmHg]	22.49±4.53	16.86±8.13	21.08±5.78
Blood bicarbonate ions at exercise stage 4 [mmol/L]	18.88±3.33	19.00±1.91	18.91±2.96
Total blood hemoglobin at exercise stage 4 [g/dL]	15.49±1.22	14.03±.67	15.13±1.27

When HCO_3 is out of range, it is either acidotic (<22 mEq/L) or alkalotic (>26 mEq/L). It is said to be normal acidotic when in the range of 22 to <24 mEq/L, and normal alkalotic when in the range of >24 to 26 mEq/L (Jindal *et al.,* 2008; West, 2008; Woodruff, 2009). For this study therefore, the average HCO_3 value for participants' arterial blood recorded is normal acidotic at rest (22.76±1.48 mmol/L), and acidotic at sub-maximal (18.91±2.96 mmol/L) and at maximal (17.80±3.03 mmol/L) and for the extreme / lowest recorded value during exercise (17.79±3.01 mmol/L) (see Table 4.23). When values for each gender are considered separately, the

only difference is that female participants were slightly acidotic at rest (21.93±2.20 mmol/L) compared to male who were normal acidotic (23.04±1.21 mmol/L) (see tables 4.24 to 4.27).

Table 4.26: Maximal values for arterial blood gas variables (Mean ± SD) summarized by gender and combined/total; male (*n* = 9), female (*n* = 3), total (*n* = 12).

ABG variable	Gender		Total
	Male	Female	
Partial pressure of arterial oxygen at exercise stage 5 [mmHg]	64.53±3.58	68.75±5.34	65.59±4.26
Partial pressure of arterial carbon dioxide at exercise stage 5 [mmHg]	33.96±3.34	34.71±4.45	34.15±3.44
Arterial oxygen saturation at exercise stage 5 [%]	89.53±4.68	92.07±1.69	90.16±4.22
Normalized arterial oxygen saturation at exercise stage 5 [%]	91.90±1.34	93.34±1.52	92.26±1.47
Blood pH (acid-base level) at exercise stage 5	7.30±.09	7.33±.02	7.31±.08
Partial pressure of alveolar oxygen at exercise stage 5 [mmHg]	88.82±3.05	88.45±5.72	88.73±3.57
Alveolar to arterial oxygen partial pressure difference at exercise stage 5 [mmHg]	24.29±4.80	19.70±11.01	23.14±6.56
Blood bicarbonate ions at exercise stage 5 [mmol/L]	17.58±3.35	18.43±2.15	17.80±3.03
Total blood hemoglobin at exercise stage 5 [g/dL]	15.78±1.34	14.00±.66	15.33±1.43

Matching the abnormal result $PaCO_2$ and HCO_3 with the pH indicates that the change in pH matches the change in HCO_3 as they are both acidic (during exercise). According to Jindal *et al.* (2008), West (2008) and Woodruff (2009), if $PaCO_2$ or HCO_3 changes in the same direction as pH, then this variable indicates the system which is responsible for causing the abnormal acid-base condition (acidosis in this case). Respiratory (lungs) system if $PaCO_2$, or Metabolic (kidneys) system if HCO_3 matches pH status. From the study data, the HCO_3 matches pH, and therefore means that the condition present is metabolic acidosis.

Checking whether the $PaCO_2$ or HCO_3 changed in the opposite direction of the pH establishes that $PaCO_2$ does, as the values are alkalotic while pH is acidotic. According to Jindal *et al.* (2008) and Woodruff (2009), if $PaCO_2$ or HCO_3 changes in the opposite direction as pH, then this variable indicates the system involved in compensation to try to correct the abnormal condition (acidosis in this case). Compensation occurs to maintain acid-base balance, from the opposing system to the one causing imbalance -either respiratory ($PaCO_2$) or metabolic (HCO_3). In the case of this study, respiratory system is involved in compensation. Compensation can be partial (if pH remains abnormal), or complete (if the pH returns to normal). In this case it is complete at resting stage and partial during sub-maximal, maximal exercise and for the extreme / lowest recorded value during exercise, as the pH remains out of normal range.

Table 4.27: Extreme (lowest or highest) values for arterial blood gas variables (Mean±SD) summarized by gender and combined/total; male (n = 9), female (n = 3), total (n = 12).

ABG variable	Gender		Total
	Male	Female	
Lowest partial pressure of arterial oxygen during exercise [mmHg]	62.49±3.58	67.28±4.87	63.69±4.28
Highest partial pressure of arterial carbon dioxide during exercise [mmHg]	35.75±3.55	37.27±5.22	36.13±3.82
Lowest arterial oxygen saturation during exercise [%]	89.42±4.59	91.50±2.16	89.94±4.13
Lowest normalized arterial oxygen saturation during exercise [%]	91.26±1.23	92.96±1.37	91.69±1.43
Lowest blood pH (acid-base level) -inverse/negative logarithm of blood hydrogen ions molar concentration, during exercise	7.30±.09	7.31±.01	7.30±.08
Highest partial pressure of alveolar oxygen during exercise [mmHg]	89.61±3.14	89.78±6.34	89.65±3.81
Highest alveolar to arterial oxygen partial pressure difference during exercise [mmHg]	24.50±4.68	20.08±10.72	23.39±6.39
Lowest blood bicarbonate ions during exercise [mmol/L]	17.57±3.33	18.43±2.15	17.79±3.01
Highest total blood hemoglobin during exercise[g/dL]	15.81±1.34	14.43±1.06	15.47±1.38

According to Nielsen (2003), Dempsey and Wagner (1999), and Miyachi and Shibayama (1992), exercise-induced arterial hypoxemia is experienced when haemoglobin O_2 saturation (SaO_2) falls below 95%. Dempsey and Wagner (1999) declares that mild EIAH would correspond to an absolute SaO_2 of 93-95%; moderate EIAH to an absolute SaO_2 in the range of 88-93%; and severe EIAH to SaO_2 values <88%. The absolute SaO_2 at maximal (89.53±4.68[male], 92.07±1.69[female], 90.16±4.22[total] %) (Table 4.26) and the lowest values (89.42±4.59[male], 91.50±2.16[female], 89.94±4.13[total] %) (Table 4.27) indicates therefore that Kenyan runners experience moderate EIAH at the testing / moderate altitude.

4.6.2. Repeated Measures Analyses of Arterial Blood Gas Values

Repeated measures / paired samples *t* test analyses were performed for the different arterial blood gas (ABG) variables to compare sub-maximal and maximal values. The *t* statistic values and the corresponding *p* values for each of the ABG parameter are shown in Table 4.28. Sub-maximal and maximal ABG values were similarly compared to extreme values i.e. the peak (highest recorded) values or minimum (lowest recorded) values, as per the way the parameter values affect endurance performance (see tables 4.29 and 4.30).

Comparison of sub-maximal (exercise stage 4) and maximal (exercise stage 5) pairs of ABG variables showed significant difference in the participants' blood pH (p = .020), blood bicarbonate ions (p < .001), total blood haemoglobin (p = .030) and alveolar to arterial oxygen partial pressure difference (p = .014). The other ABG variables did not differ significantly between sub-maximal and maximal levels (partial pressure of arterial oxygen p = .208, partial pressure of arterial carbon dioxide p = .941, normalized arterial oxygen saturation p = .147 and partial pressure of

alveolar oxygen p = .284). Absolute arterial oxygen saturation values indicated significant difference (p = .014) but when considered under normal body temperature, pH and CO_2, the values were not significantly different. Although A-aDO_2 recorded significant difference between sub-maximal and maximal levels, the value is still within the normal range (only that male runners were at the extreme end of the normal range), judged by observations from ATS/ACCP (2003).

Table 4.28: Paired samples *t* test comparing sub-maximal and maximal ABG values (n = 12).

ABG variables in sub-maximal and maximal pairs		Paired Differences			*t*	*df*	Sig. (2-tailed)
		Mean	Std. Dev.	SE Mean			
Pair 1	Partial pressure of arterial oxygen at exercise stage 4 [mmHg] - Partial pressure of arterial oxygen at exercise stage 5 [mmHg]	1.472	3.814	1.101	1.337	11	.208
Pair 2	Partial pressure of arterial carbon dioxide at exercise stage 4 [mmHg] - Partial pressure of arterial carbon dioxide at exercise stage 5 [mmHg]	.040	1.813	.5233	.076	11	.941
Pair 3	Arterial oxygen saturation at exercise stage 4 [%] - Arterial oxygen saturation at exercise stage 5 [%]	1.363	1.618	.4671	2.917	11	.014
Pair 4	Normalized arterial oxygen saturation at exercise stage 4 [%] - Normalized arterial oxygen saturation at exercise stage 5 [%]	.4763	1.057	.3052	1.561	11	.147
Pair 5	Blood pH (acid-base level) at exercise stage 4 - Blood pH (acid-base level) at exercise stage 5	.0227	.0290	.0084	2.710	11	.020
Pair 6	Partial pressure of alveolar oxygen at exercise stage 4 [mmHg] - Partial pressure of alveolar oxygen at exercise stage 5 [mmHg]	-.5918	1.819	.5250	-1.127	11	.284
Pair 7	Alveolar to arterial oxygen partial pressure difference at exercise stage 4 [mmHg] - Alveolar to arterial oxygen partial pressure difference at exercise stage 5 [mmHg]	-2.064	2.439	.7041	-2.932	11	.014
Pair 8	Blood bicarbonate ions at exercise stage 4 [mmol/L] - Blood bicarbonate ions at exercise stage 5 [mmol/L]	1.113	.7784	.2247	4.951	11	.000
Pair 9	Total blood hemoglobin at exercise stage 4 [g/dL] - Total blood hemoglobin at exercise stage 5 [g/dL]	-.2083	.2899	.0837	-2.490	11	.030

Table 4.29: Paired samples *t* test comparing maximal and extreme ABG values (*n* = 12).

Paired variables		Paired Differences			*t*	*df*	Sig.(2-tailed)
		Mean	Std. Dev.	SE Mean			
Pair 1	Partial pressure of arterial oxygen at exercise stage 5 [mmHg] - Lowest partial pressure of arterial oxygen during exercise [mmHg]	1.902	2.007	.5794	3.283	11	.007
Pair 2	Partial pressure of arterial carbon dioxide at exercise stage 5 [mmHg] - Highest partial pressure of arterial carbon dioxide during exercise [mmHg]	-1.983	1.281	.3698	-5.361	11	.000
Pair 3	Arterial oxygen saturation at exercise stage 5 [%] - Lowest arterial oxygen saturation during exercise [%]	.2208	.4717	.1362	1.622	11	.133
Pair 4	Normalized arterial oxygen saturation at exercise stage 5 [%] - Subject's lowest normalized arterial oxygen saturation during exercise [%]	.5767	.6688	.1931	2.987	11	.012
Pair 5	Blood pH (acid-base level) at exercise stage 5 - Lowest blood pH (acid-base level) during exercise	.0049	.0102	.0029	1.653	11	.126
Pair 6	Partial pressure of alveolar oxygen at exercise stage 5 [mmHg] - Highest partial pressure of alveolar oxygen during exercise [mmHg]	-.9232	.8324	.2403	-3.842	11	.003
Pair 7	Alveolar to arterial oxygen partial pressure difference at exercise stage 5 [mmHg] - Highest alveolar to arterial oxygen partial pressure difference during exercise [mmHg]	-.2483	.4019	.1160	-2.140	11	.056
Pair 8	Blood bicarbonate ions at exercise stage 5 [mmol/L] - Lowest blood bicarbonate ions during exercise [mmol/L]	.0083	.0289	.0083	1.000	11	.339
Pair 9	Total blood hemoglobin at exercise stage 5 [g/dL] - Highest total blood hemoglobin during exercise [g/dL]	-.1333	.3725	.1075	-1.240	11	.241

Significant difference was recorded between sub-maximal and maximal values in pH, HCO_3, SaO_2, A-aDO_2 and tHb (Table 4.28), and between maximal and extreme recorded values in PaO_2, $PaCO_2$, SaO_2n and PAO_2 (Table 4.29). Sub-maximal and extreme recorded values were significantly different in all ABG variables (Table 4.30).

Table 4.30: Paired samples *t* test comparing sub-maximal and extreme values (*n* = 12).

Paired variables	Paired Differences			*t*	*df*	Sig. (2-tailed)
	Mean	Std. Dev.	SE Mean			
Pair 1 Partial pressure of arterial oxygen at exercise stage 4 [mmHg] - Lowest partial pressure of arterial oxygen during exercise [mmHg]	3.375	4.041	1.166	2.893	11	.015
Pair 2 Partial pressure of arterial carbon dioxide at exercise stage 4 [mmHg] - Highest partial pressure of arterial carbon dioxide during exercise [mmHg]	-1.943	1.909	.5511	-3.526	11	.005
Pair 3 Arterial oxygen saturation at exercise stage 4 [%] - Lowest arterial oxygen saturation during exercise [%]	1.583	1.366	.3943	4.016	11	.002
Pair 4 Normalized arterial oxygen saturation at exercise stage 4 [%] - Subject's lowest normalized arterial oxygen saturation during exercise [%]	1.053	1.208	.3488	3.019	11	.012
Pair 5 Blood pH (acid-base level) at exercise stage 4 - Lowest blood pH (acid-base level) during exercise	.0276	.0224	.0065	4.260	11	.001
Pair 6 Partial pressure of alveolar oxygen at exercise stage 4 [mmHg] - Highest partial pressure of alveolar oxygen during exercise [mmHg]	-1.515	1.627	.4696	-3.226	11	.008
Pair 7 Alveolar to arterial oxygen partial pressure difference at exercise stage 4 [mmHg] - Highest alveolar to arterial oxygen partial pressure difference during exercise [mmHg]	-2.312	2.281	.6585	-3.511	11	.005
Pair 8 Blood bicarbonate ions at exercise stage 4 [mmol/L] - Lowest blood bicarbonate ions during exercise [mmol/L]	1.121	.7683	.2218	5.054	11	.000
Pair 9 Total blood hemoglobin at exercise stage 4 [g/dL] - Highest total blood hemoglobin during exercise [g/dL]	-.3417	.3698	.1067	-3.201	11	.008

Repeated measures ANOVA were performed for the different ABG variables to compare values from different exercise stages / intensities. Illustrations of the trend in different ABG variables are presented in figures 4.6 to 4.11. The *F* statistic values and the corresponding *p* values as well as sphericity and intraclass correlation test results for each of the various ABG parameters are shown in tables 4.31 to 4.36.

4.6.2.1. Acid-Base (pH) Values

The pH variable is normally expected to reduce (become more acidic) with increasing exercise intensity. Values of 7.07 and 6.88 have been reported with maximal endurance exercise by Nielsen *et al.* (2002) and Jubrias *et al.* (2003) respectively. Values recorded during the study indicates similar tread (see Figure 4.6), but with the average lowest pH of 7.30 reached at termination of exercise for male runners.

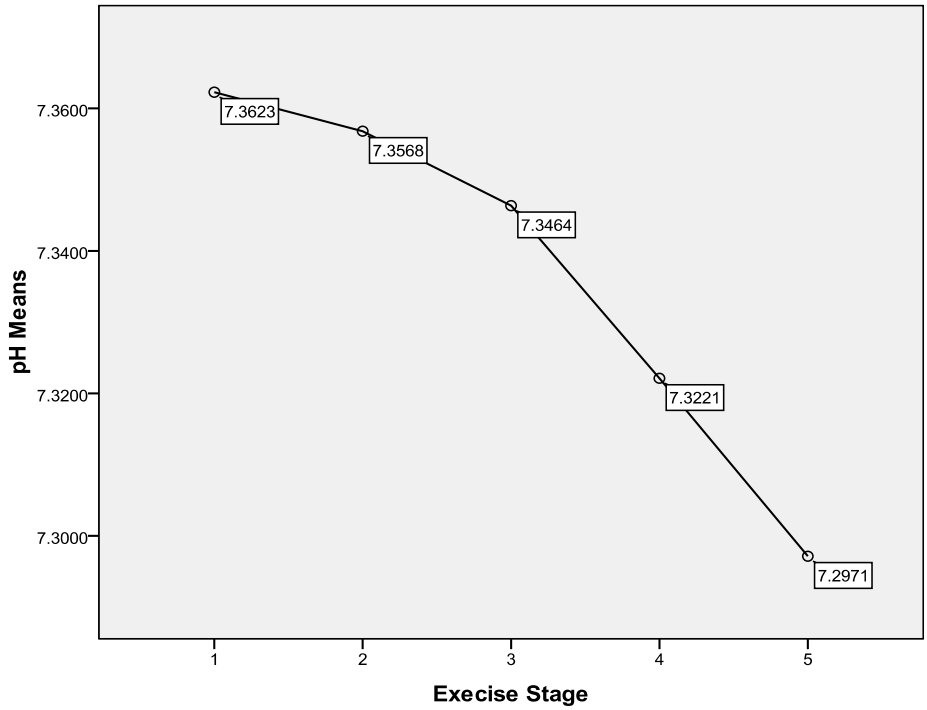

Figure 4.6: Means of pH values for five exercise stages leading to maximal endurance treadmill run for male runners (n = 9).

Table 4.31a: Repeated measures ANOVA test comparing pH values for three exercise stages leading to maximal endurance treadmill run for both male and female (n =12).

		Sum of Squares	*df*	Mean Square	*F*	Sig
Between People		.173	11	.016		
Within People	Between Items	.014	2	.007	16.340	.000
	Residual	.009	22	.000		
	Total	.023	24	.001		
Total		.196	35	.006		

Grand Mean = 7.329914 Within-subject effects is significant at the .01 level

Table 4.31b: Pairwise comparison of pH values for three exercise stages leading to maximal endurance treadmill run (*n* =12).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
3	4	.025*	.004	.000	.015	.035
	5	.048*	.011	.001	.024	.071
4	3	-.025*	.004	.000	-.035	-.015
	5	.023*	.008	.020	.004	.041
5	3	-.048*	.011	.001	-.071	-.024
	4	-.023*	.008	.020	-.041	-.004

*. The mean difference is significant at the .05 level.

Table 4.31c: Pairwise comparison of sub-maximal, maximal and extreme (stages 4, 5 and lowest pH values) (*n* = 12).

(I) Execise Stage	(J) Execise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
4	low	.028*	.006	.001	.013	.042
	5	.023*	.008	.020	.004	.041
low	4	-.028*	.006	.001	-.042	-.013
	5	-.005	.003	.126	-.011	.002
5	4	-.023*	.008	.020	-.041	-.004
	low	.005	.003	.126	-.002	.011

*. The mean difference is significant at the .05 level.

Acid-base (pH) values recorded during the maximal stage of the test (stage 5) are significantly different from sub-maximal values, and do not differ significantly from lowest values recorded during the test. This indicates that pH (or variable/s associated with it) is a critical limiting factor to endurance performance in the Kenyan runners. Factors associated with regulating pH during endurance exercise include hyperventilation and body buffer systems.

4.6.2.2. Bicarbonate Ions (HCO_3)

The bicarbonate ions (HCO_3) are normally expected to decrease with increasing exercise intensity. This is due to increased lactate associated with higher exercise intensities using up the HCO_3. Values of 22 to 26 mmol/L are considered to be a normal range at rest (Jindal *et al.,* 2008; Woodruff, 2009). Values recorded during the current study indicate the expected tread (see Figure 4.7), but with the extreme values dropping to 17.38 mmol/L.

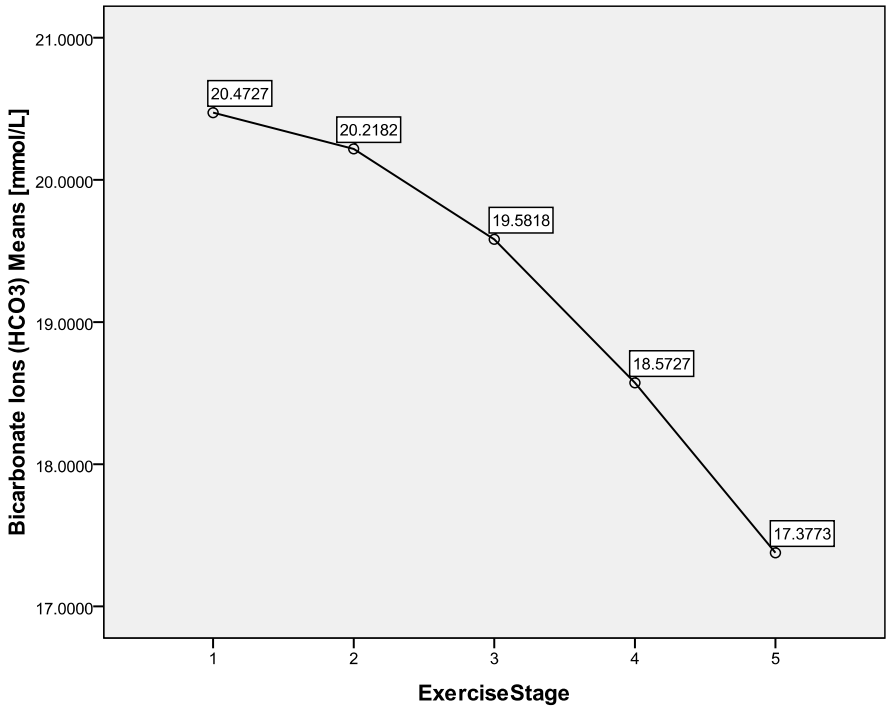

Figure 4.7: Bicarbonate ions (HCO_3) means [mmol/L] for five exercise stages leading to maximal endurance treadmill run (n =12).

Table 4.32a: Repeated measures ANOVA test comparing bicarbonate ions (HCO_3) for three exercise stages leading to maximal endurance treadmill run (n =12).

		Sum of Squares	*df*	Mean Square	*F*	Sig
Between People		258.741	11	23.522		
Within People	Between Items	25.376	2	12.688	28.790	.000
	Residual	9.696	22	.441		
	Total	35.072	24	1.461		
Total		293.812	35	8.395		

Grand Mean = 18.851389 Within-subject effects is significant at the .01 level

Table 4.32b: Pairwise comparison of bicarbonate ions (HCO_3) for three exercise stages leading to maximal endurance treadmill run (n =12).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
3	4	.942*	.209	.001	.482	1.402
	5	2.054*	.355	.000	1.272	2.836
4	3	-.942*	.209	.001	-1.402	-.482
	5	1.113*	.225	.000	.618	1.607
5	3	-2.054*	.355	.000	-2.836	-1.272
	4	-1.113*	.225	.000	-1.607	-.618

*. The mean difference is significant at the .05 level.

Table 4.32c: Pairwise comparison of sub-maximal, maximal and extreme bicarbonate ions (HCO_3) values (n = 12) (stage 4, 5 and lowest).

(I) Execise Stage	(J) Execise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
4	low	1.121*	.222	.000	.633	1.609
	5	1.113*	.225	.000	.618	1.607
low	4	-1.121*	.222	.000	-1.609	-.633
	5	-.008	.008	.339	-.027	.010
5	4	-1.113*	.225	.000	-1.607	-.618
	low	.008	.008	.339	-.010	.027

*. The mean difference is significant at the .05 level.

Bicarbonate ions values recorded during the maximal stage of the test (stage 5) are significantly different from sub-maximal values (recorded in stage 4), and do not differ significantly from lowest values recorded during the test. This indicates that HCO_3 (or variable/s associated with it) is a critical limiting factor to endurance performance in the Kenyan runners. Bicarbonate ions are involved in buffering acidosis associated with blood lactate from high exercise intensity, but gets depleted because the replenishing system in the kidney is slow.

4.6.2.3. Arterial Blood Oxygen Saturation (SaO_2)

Arterial blood oxygen saturation variable is normally expected to decrease with increasing exercise intensity. Values lower than 88% have been reported at maximal exercise (Dempsey & Wagner, 1999). Values recorded in the current study indicate normal decreasing tread (see Figure 4.8) but with maximal values not dropping as much.

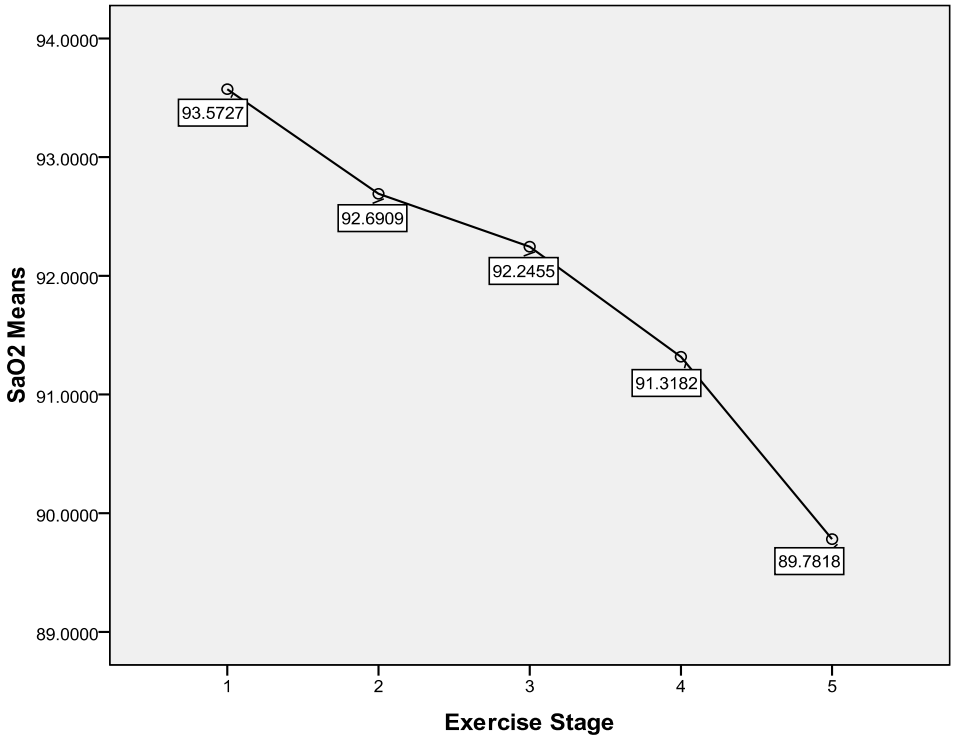

Figure 4.8: Arterial blood oxygen saturation (SaO_2) means for five exercise stages leading to maximal endurance treadmill run (n =12).

Table 4.33a; Repeated measures ANOVA test comparing arterial blood oxygen saturation for three exercise stages leading to maximal endurance treadmill run (n =12).

		Sum of Squares	*df*	Mean Square	*F*	Sig
Between People		529.214	11	48.110		
Within People	Between Items	34.429	2	17.214	18.547	.000
	Residual	20.420	22	.928		
	Total	54.848	24	2.285		
Total		584.062	35	16.687		

Grand Mean = 91.412500 Within-subject effects is significant at the .01 level

Table 4.33b: Pairwise comparison of arterial blood oxygen saturation (SaO_2) three exercise stages leading to maximal endurance treadmill run (n =12).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
3	4	1.025*	.209	.000	.566	1.484
	5	2.388*	.450	.000	1.397	3.378
4	3	-1.025*	.209	.000	-1.484	-.566
	5	1.363*	.467	.014	.334	2.391
5	3	-2.388*	.450	.000	-3.378	-1.397
	4	-1.363*	.467	.014	-2.391	-.334

*. The mean difference is significant at the .05 level.

Table 4.33c: Pairwise comparison of sub-maximal, maximal and extreme (stages 4, 5 and lowest values) arterial blood oxygen saturation (SaO_2) values (n = 12).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
4	low	1.583*	.394	.002	.715	2.451
	5	1.363*	.467	.014	.334	2.391
low	4	-1.583*	.394	.002	-2.451	-.715
	5	-.221	.136	.133	-.521	.079
5	4	-1.363*	.467	.014	-2.391	-.334
	low	.221	.136	.133	-.079	.521

*. The mean difference is significant at the .05 level.

Arterial blood oxygen saturation (SaO_2) values recorded during the maximal stage of the test (stage 5) are significantly different from sub-maximal values (recorded in stage 4), and do not differ significantly from lowest values recorded during the test. This indicates that SaO_2 (or variable/s associated with it) is a critical limiting factor to endurance performance in the Kenyan runners. Factors associated with reduced arterial blood oxygen saturation include low pH (acidosis), high body temperature, and low arterial partial pressure of oxygen.

4.6.2.4. Alveolar to Arterial Oxygen Difference

The alveolar to arterial oxygen difference (A-aDO_2) is normally expected to with increasing exercise intensity. Values of 10 mmHg at rest and as high as 24 mmHg during maximal exercise are expected among normal individuals, while values greater than 35 mmHg indicate possible gas exchange abnormality (ATS/ACCP, 2003; Plowman & Smith, 1997). Values recorded during the current study (17 to 24 mmHg) indicate a normal tread (Figure 4.9).

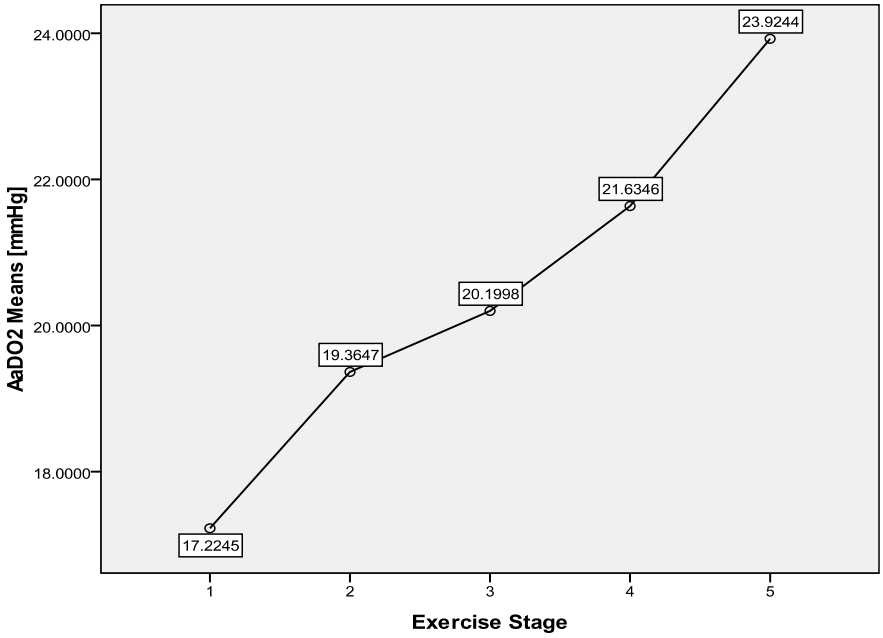

Figure 4.9: Alveolar to arterial oxygen difference (A-aDO_2) means for five exercise stages leading to maximal endurance treadmill run (n =12).

Table 4.34a: Repeated measures ANOVA test comparing alveolar to arterial blood oxygen difference (A-aDO_2) for three exercise stages leading to maximal stage (n =12).

		Sum of Squares	*df*	Mean Square	*F*	Sig
Between People		1173.515	11	106.683		
Within People	Between Items	84.787	2	42.394	7.915	.003
	Residual	117.829	22	5.356		
	Total	202.616	24	8.442		
Total		1376.132	35	39.318		

Grand Mean = 21.204732 Within-subject effects is significant at the .01 level

Table 4.34b: Pairwise comparison of alveolar to arterial blood oxygen difference (A-aDO_2) for three exercise stages leading to maximal endurance treadmill run (n =12).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
3	4	-1.689*	.740	.043	-3.317	-.061
	5	-3.753*	1.279	.014	-6.567	-.938
4	3	1.689*	.740	.043	.061	3.317
	5	-2.064*	.704	.014	-3.614	-.514
5	3	3.753*	1.279	.014	.938	6.567
	4	2.064*	.704	.014	.514	3.614

*. The mean difference is significant at the .05 level.

Table 4.34c: Pairwise comparison of sub-maximal, maximal and extreme alveolar to arterial blood oxygen difference (A-aDO_2) values (Stages 4, 5 and highest) (n = 12).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
4	pk	-2.312*	.659	.005	-3.762	-.863
	5	-2.064*	.704	.014	-3.614	-.514
pk	4	2.312*	.659	.005	.863	3.762
	5	.248	.116	.056	-.007	.504
5	4	2.064*	.704	.014	.514	3.614
	pk	-.248	.116	.056	-.504	.007

*. The mean difference is significant at the .05 level.

Alveolar to arterial oxygen difference (A-aDO_2) values recorded during the maximal stage of the test (stage 5) are significantly different from sub-maximal values (recorded in stage 4), and do not differ significantly from lowest values recorded during the test. This indicates that A-aDO_2 (or variable/s associated with it) is a critical limiting factor to endurance performance in the Kenyan runners. Fast blood transit time during exercise and cardio-pulmonary shunts are among the factor that may be associated with wide alveolar to arterial oxygen difference.

4.6.2.5. Total Haemoglobin

The normal ranges for total hemoglobin (tHb) in human blood are: Adult males; 14-18 gm/dl, Adult women; 12-16 gm/dl (Billett, 1990). The variable is normally expected to increase with increasing exercise intensity. This may be due to decrease in blood volume as a result of fluid shifts and fluid loss referred to in Plowman and Smith (1997) pg. 114, 342. Values recorded during the current study indicate similar tread (Figure 4.10), with a sharper increase at the maximal exercise stage.

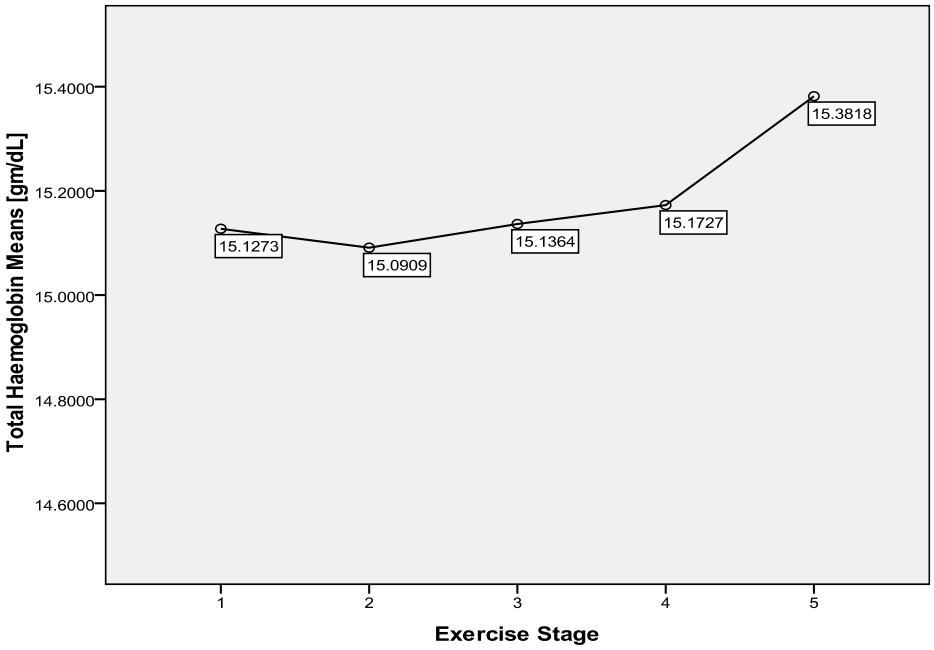

Figure 4.10: Total hemoglobin (tHb) means for five exercise stages leading to maximal endurance treadmill run (n =12).

Table 4.35a: Repeated measures ANOVA test comparing total hemoglobin (tHb) for three exercise stages leading to maximal endurance treadmill run (n =12).

		Sum of Squares	*df*	Mean Square	*F*	Sig
Between People		59.444	11	5.404		
Within People	Between Items	.377	2	.189	5.464	.012
	Residual	.759	22	.035		
	Total	1.137	24	.047		
Total		60.581	35	1.731		

Grand Mean = 15.188889 Within-subject effects is significant at the .05 level

Table 4.35b: Pairwise comparison of total hemoglobin (tHb) for three exercise stages leading to maximal endurance treadmill run (*n* =12) (Stage 3-5).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
3	4	-.017	.061	.791	-.152	.118
	5	-.225*	.081	.018	-.402	-.048
4	3	.017	.061	.791	-.118	.152
	5	-.208*	.084	.030	-.392	-.024
5	3	.225*	.081	.018	.048	.402
	4	.208*	.084	.030	.024	.392

*. The mean difference is significant at the .05 level.

Table 4.35c: Pairwise comparison of sub-maximal, maximal and extreme total hemoglobin (tHb) values (*n* = 12) (stage 4, 5 and highest).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
4	pk	-.342*	.107	.008	-.577	-.107
	5	-.208*	.084	.030	-.392	-.024
pk	4	.342*	.107	.008	.107	.577
	5	.133	.108	.241	-.103	.370
5	4	.208*	.084	.030	.024	.392
	pk	-.133	.108	.241	-.370	.103

*. The mean difference is significant at the .05 level.

Total hemoglobin (tHb) values recorded during the maximal stage of the test (stage 5) are significantly different from sub-maximal values (recorded in stage 4), and do not differ significantly from lowest values recorded during the test. This indicates that tHb (or variable/s associated with it) is a critical limiting factor to endurance performance in the Kenyan runners.

4.6.2.6. Oxygen Content

Tissues require constant supply of a requisite amount of O_2 molecules for metabolism. In order to know the quantity of oxygen in the blood, the value of oxygen content need to be established. Neither the PaO_2 nor the SaO_2 provide

information on the number of oxygen molecules is in the blood since none of them have units that denote any quantity. According to Plowman and Smith (1997), and Martin (1999), oxygen content can be measured directly or calculated by the oxygen content equation:

CaO_2 = (Hb x 1.34 x SaO_2 [expressed in decimal]) + (.00304 x PaO_2) [ml/dL]

Oxygen content in arterial blood (CaO_2) [units ml O_2/dL] gives us the quantity of oxygen that is in the arterial blood because the value incorporates the hemoglobin content. Constant 1.34 is the amount of oxygen that can bind with each gram of hemoglobin, while .00304 is the solubility index. Figure 4.11 shows oxygen content (CaO_2) mean values recorded for the five exercise stages in the current study.

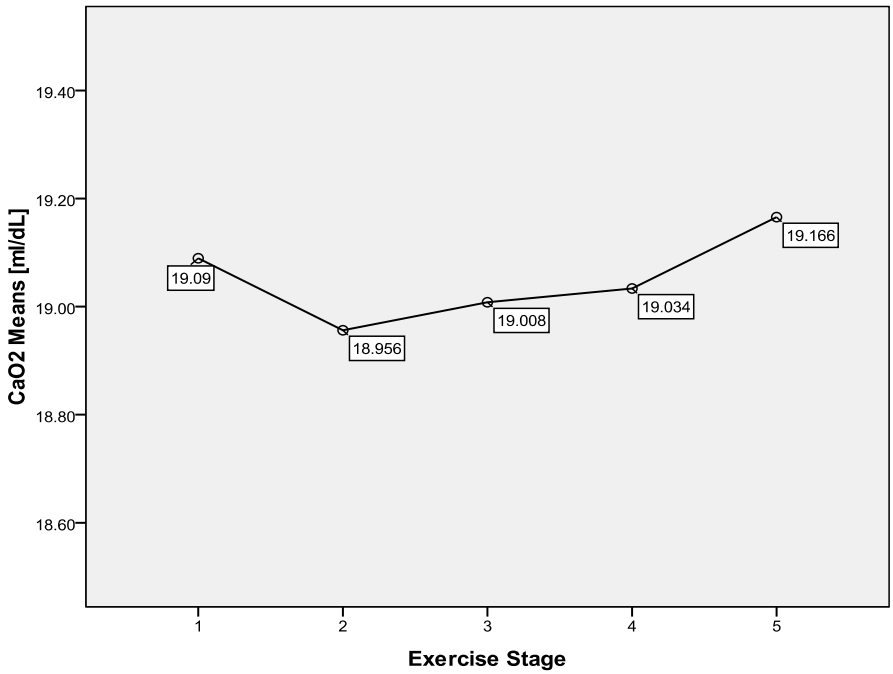

Figure 4.11: Oxygen content (CaO_2) means for five exercise stages leading to maximal endurance treadmill run (n =12).

Oxygen content variable is normally expected to be maintained with increasing exercise intensity, even at peak exercise (ATS/ACCP, 2003; Plowman & Smith,

1997). Values recorded during the study indicate that there was no significant change across the different exercise stages. The marginal increase in the variable at maximal exercise stage may be attributed to the increase in tHb (figures 4.10 and 4.11).

Table 4.36a: Repeated measures ANOVA test comparing oxygen content (CaO_2) for three exercise stages leading to maximal endurance treadmill run (n =12) (Stage 3-5).

		Sum of Squares	*df*	Mean Square	*F*	Sig
Between People		77.871	11	7.079		
Within People	Between Items	.159	2	.080	.856	.439
	Residual	2.046	22	.093		
	Total	2.206	24	.092		
Total		80.077	35	2.288		

Grand Mean = 19.0495 Within-subject effects is not significant

Table 4.36b: Pairwise comparison of sub-maximal, maximal and extreme oxygen content (CaO_2) values (n = 12) (stage 4, 5 and lowest).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
4	low	.358*	.084	.001	.174	.543
	5	-.151	.129	.265	-.435	.132
low	4	-.358*	.084	.001	-.543	-.174
	5	-.510*	.104	.000	-.738	-.281
5	4	.151	.129	.265	-.132	.435
	low	.510*	.104	.000	.281	.738

*. The mean difference is significant at the .05 level.

Oxygen content maximal values (recorded during the maximal stage of the test) are not significantly different from sub-maximal values, and do differ significantly from extreme (lowest and highest) values recorded during the test. This indicates that CaO_2 is not a critical limiting factor to endurance performance (in the Kenyan runners). The variable values tended to increase, albeit marginally.

Table 4.36c: Pairwise comparison of sub-maximal, maximal and extreme oxygen content (CaO_2) values (n = 12) (stage 4, 5 and highest).

(I) Exercise Stage	(J) Exercise Stage	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
4	pk	-.531*	.158	.006	-.879	-.183
	5	-.151	.129	.265	-.435	.132
pk	4	.531*	.158	.006	.183	.879
	5	.380*	.168	.045	.009	.750
5	4	.151	.129	.265	-.132	.435
	pk	-.380*	.168	.045	-.750	-.009

*. The mean difference is significant at the .05 level.

4.6.3. Arterial Blood Gas vs Endurance Performance Correlation Analysis

Pearson correlation analysis between ABG variables and performance indices such as VO_2submax, VO_2max, sub-maximal speed and speed at maximal exercise stage showed no significant relationships ($p > .05$). It is important therefore for future studies to establish the relationship, extent and mechanism of the effects of the changes in arterial blood variables on endurance performance.

4.7. Reliability Indices

Reliability for the data collection instruments and procedures was analysed using Intraclass correlation as it is appropriate for study based on repeated measures/ within subject design. Test of normality and sphericity were used to establish whether the data conformed to the assumption of normality and compound symmetry respectively, as per the requirement of the repeated measures / within subjects study design. Effect size (Eta Squared) was also generated to judge practical significance of the results. These tests and their outputs are given in the following subsections:

4.7.1. Intraclass Correlation Coefficient Analyses

Output tables for Intraclass correlation coefficient analyses for the three exercise stages leading to the maximal stage are presented for the various variables in the preceding sections. The analyses showed high/acceptable reliability coefficient for most variables and the associated procedures (R = .973[VE], .976[Fb], .976[RER], .954[rVO_2], .974[pH], .981[HCO_3], .981[SaO_2], .950[$AaDO_2$], .994[tHb] and .987[CaO_2]) (see Appendix VI, tables 4.17f, 4.18f, 4.19f, 4.21f, 4.31f, 4.32f 4.33f, 4.34f, 4.35f and 4.36f respectively). According to Vincent (1995), Intraclass Correlation Coefficient of .80 and above is acceptable for it indicates high reliability of the test instruments and procedures.

4.7.2. Tests for Normality and Sphericity

Subject's recoded values were confirmed as normally distributed for both males and females using Shapiro-Wilk's test ($p > .05$). Results of these analyses for rVO_2 at maximal exercise (stage 5) are shown in Table 4.37. Mauchly's test of within-subject effects was used to determine if the data met the assumption for sphericity / compound symmetry ($p > .05$) as required by within subject designs (repeated measures t and F tests). When "Sig." values are greater than .05 the result indicate conformity to the requirement of sphericity. According to Vincent (1995), epsilon values generated are used to adjust degree of freedom for the test to determine significant values in F distribution. Acceptable Huynh-Feldt epsilon values close to and over .75 were recorded (ε = .69[VE], .88[Fb], .64[RER], .70[rVO_2], .63[pH], .71[HCO_3], .71[SaO_2], .62[$AaDO_2$], 1.00[tHb] and .97[CaO_2]) (see Appendix VI, tables 4.17d, 4.18d, 4.19d, 4.21d, 4.31d, 4.32d, 4.33d, 4.34d, 4.35d and 4.36d respectively). This was especially the case for the data from the exercise stages just

prior to termination of the exercise i.e. sphericity improved / increased towards later stages of the exercise. This may be due to the fact that the athletes were at different percentage of their maximum effort during the earlier exercise stages (only the last five exercise stages were picked for each athlete for these analyses).

Table 4.37: Shapiro-Wilk's test of Normality on subjects' rate of oxygen consumption relative to body weight (rVO_2), $p > .05$ indicating that the recorded values were normally distributed for both males and females.

	Subject's gender	Shapiro-Wilk		
		Statistic	*df*	Sig.
Subject's rate of oxygen consumption relative to body weight (rVO2) at exercise stage 5 [ml/kg/min]	Male	.934	10	.491
	Female	.815	4	.131

Shapiro-Wilk test is testing the null hypothesis that the data's distribution is equal to a normal distribution. Rejecting the null hypothesis means that the data's distribution is not equal to a normal distribution, while accepting the null hypothesis means that the data's distribution is equal to a normal distribution. Both the "Sig." values in the table are greater than .05 (.491 and .131 for male and female respectively). Therefore, the dependent variable, rVO_2, is normally distributed for each category (i.e., "males" and "females") of the independent variable, gender.

4.7.3. Effect Size

Outputs for effect size (Eta Squared) were generated with each repeated measures ANOVA and the values range indicate the differences recorded were of practical significance, except in CaO_2 which did not register statistical or practical significance (Eta Sqd. = .604[VE], .285[Fb], .676[RER], .456[rVO_2], .598[pH], .724[HCO_3], .628[SaO_2], .418[A-aDO_2], .332[tHb] and .072[CaO_2) (see Appendix VI, tables 4.17e, 4.18e, 4.19e, 4.21e, 4.31e, 4.32e, 4.33e, 4.34e, 4.35e and 4.36e respectively). According to Vincent (1995), Eta Squared values of .30 and above indicate practical significance in the difference recorded. The changes in most of the variables are therefore hugely attributable to change in exercise stage / increased level of intensity.

4.8. Summary of Addressed Research Questions

The main research objective was to investigate whether Kenyan elite distance runners have enhanced pulmonary ability to transfer respiratory gasses from air to the blood and vice versa, and whether their pulmonary function parameters are related to their performance during sub-maximal and maximal endurance exercise. To achieve the research specific objectives, four research questions were addressed as presented in the following subsections:

4.8.1. Rating Spirometric and Exercise Respiratory Values against Norms

The first research question involved rating baseline spirometric and exercising respiratory values against predicted norms. From the results presented in section 4.3, there was no significant difference between most spirometric values and the predicted values for male runners (p = .274[PEF], .118[FVC], .184[FEV_1], .281[FEV_1/FVC]) (see table 4.7). A few of the variables values however rated lower than predicted in female runners (p = .030[PEF], .025[FVC], .033[FEV]) (see table 4.8). The results presented in section 4.5 indicate that oxygen consumption relative to body weight (rVO_2) at sub-maximal and maximal exercise stages rated excellent and superior on the table of established norms. Sub-maximal value of rVO_2 do not differ significantly from maximal value (p = .739). This means there is relatively high rate of oxygen consumption which can be sustained.

4.8.2. Status of Ventilatory Response and Acid-Base Level

The second research question involved finding out the extent Kenyan elite distance runners experience inadequate hyperventilation response to acid-base status (metabolic acidosis) during sub-maximal and maximal endurance exercise. The results presented in section 4.6 indicate that Kenyan runners experience moderate

metabolic acidosis during sub-maximal (pH = 7.33±.07, $PaCO_2$ = 34.19±4.77 mmHg and HCO_3 = 18.91±2.96 mEq/L) and maximal endurance exercise (pH = 7.31±.08, $PaCO_2$ = 34.15±3.44 mmHg and HCO_3 = 17.80±3.03 mEq/L) (see Tables 4.24). The extreme values recorded during exercise were (pH = 7.30±.09, $PaCO_2$ = 35.75±3.55 mmHg and HCO_3 = 17.57±3.33 mEq/L) and (pH = 7.31±.01, $PaCO_2$ = 37.27±5.22 mmHg and HCO_3 = 18.43±2.15 mEq/L) for males and female runners respectively (see tables 4.24 to 4.27). The results presented in section 4.6.1 indicate that Kenyan elite distance runners experience sufficient hyperventilation to keep $PaCO_2$ within normal range, and to partially compensate for metabolic acidosis during sub-maximal and maximal endurance exercise. Respiratory compensation is notable as the $PaCO_2$ status is towards the opposite direction (from the normal 40 mmHg to alkaloic 34.15±3.44 mmHg) of the acid-base status (from the normal pH of 74 to acidotic 7.31±.08).

4.8.3. Status and Extent of Exercise-Induced Arterial Hypoxemia

The third research question involved finding out the extent Kenyan elite distance runners experience exercise-induced arterial hypoxemia. The results presented in section 4.6.1 indicate that Kenyan elite distance runners only experience moderate level of exercise-induced arterial hypoxemia during sub-maximal endurance exercise (SaO_2 = 91.12±4.27[male], 92.73±2.65[female] %), and maximal endurance exercise (SaO_2 = 89.53±4.68[male], 92.07±1.69[female] %) (see Table 4.25 and Table 4.26). The results presented in section 4.6.1 indicate that Kenyan elite distance runners do not suffer excessive alveolar to arterial oxygen difference beyond normal levels (A-aDO_2 < 24 mmHg) during sub-maximal (22.49±4.53[male], 16.86±8.13[female] mmHg) and maximal (24.29±4.80[male], 19.70±11.01[female] mmHg) endurance exercise (see Table 4.25 and Table 4.26).

4.8.4. Pulmonary Function Variables vs Endurance Performance

The fourth research question involved finding out whether there are significant relationships between pulmonary function parameters and endurance exercise performance indicators among Kenyan elite distance runners. The results presented in section 4.5.3 (Table 4.22) indicate that some pulmonary function parameters correlate highly with indicators of performance (high sub-maximal speed/velocity, and high sub-maximal VO_2) during sub-maximal endurance exercise. FVC and VE had significant correlation with rVO_2 both at sub-maximal and maximal levels. PEF (r = .625, p = .017), FVC (r = .741, p = .002), FEV_1 (r = .658, p = .010), VE (r = .792, p = .001) and Velocity (r = .670, p = .009) had higher correlation with rVO_2 at sub-maximal than at maximal levels. Fb had significant correlation with rVO_2 at maximal level but no significant correlation at sub-maximal level. But other variables (PIF, FEV_1/FVC, MIP, Vt, %MHR and RER) had no significant correlation with rVO_2 at sub-maximal and maximal endurance exercise. The results presented in section 4.6.3 indicate that there is no significant correlation between ABG variables and performance indices such as VO_2submax, VO_2max, sub-maximal speed and maximal speed attained during the incremental endurance exercise ($p > .05$).

4.9. Spurious Relationships

The heart rate and anthropometric data were taken as spurious data i.e. important data but which have no direct implication on answering the research questions –not used in hypothesis testing. Running economy and Ventilation threshold are also explored. The data for these variables are analysed and possible relationships with other research variables explored in the following subsection.

4.9.1. Heart Rate Data and Endurance Performance

Heart rate increases proportionately with exercise intensity (linearly with VO_2) (Haff & Dumke, 2012; Plowman & Smith, 1997). The variable values are influenced by an individual's age and level of cardio-respiratory fitness. Percent of maximum heart rate (%MHR) at rest and during exercise have been used to predict cardio-respiratory fitness, with the maximum heart rate (MHR) measured directly, or estimated from age-based formulae. In the current study MHR was estimated from 220 – age formula.

The recorded HR values show a linear increment with exercise intensity (see Figure 4.12). The *t* test comparing the heart rate values recorded and age-predicted values indicate that the participants had significantly lower MHR and %MHR (p = .001) at different exercise stages (see Table 4.38). Lower heart rate is a hallmark of adaptation to endurance training (Haff & Dumke, 2012; Plowman & Smith, 1997). According to the authors, the reduction of HR following training results from increased stroke volume rather than reduction in VO_2 or cardiac output. It is therefore logical to say that the subjects in the current study had high stroke volume.

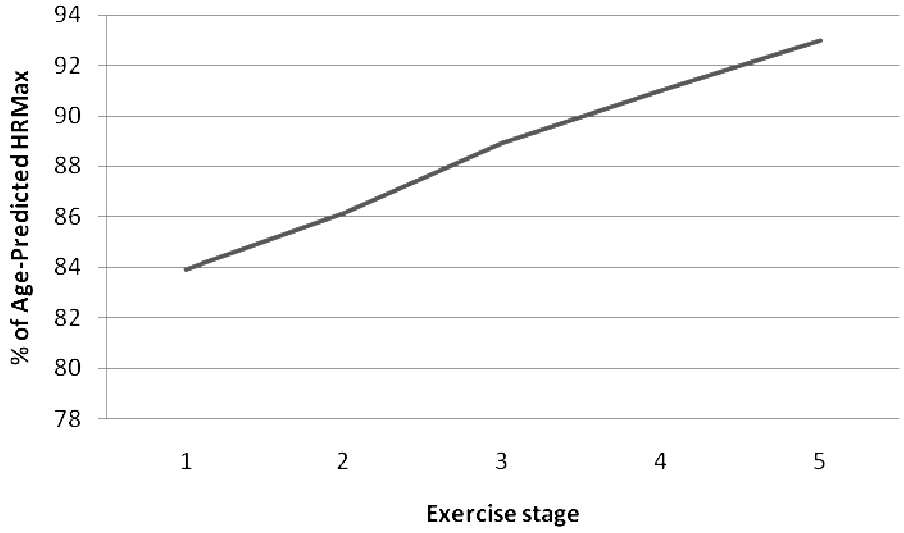

Figure 4.12; Percent of age-predicted maximum heart rate recorded during five exercise stages leading to maximal / termination of exercise (n = 13).

Table 4.38: One-Sample *t* test comparing percent of age-predicted maximum heart rate at termination of exercise and the age-predicted maximum heart rate (100%) (*n* = 13).

	Test Value = 100			
	t	*df*	Sig. (2-tailed)	Mean Difference
Percent of age-predicted maximum heart rate recorded at termination of exercise [%]	-4.584	12	.001	-7.0161538

4.9.2. Anthropometric Data and Endurance Performance

The study participants' anthropometric values are summarised in Table 4.39 below. The somatotype values were calculated using Heath-Carter formula as adopted in ISAK Manual (Marfell-Jones *et al.,* 2006). The values indicate that the participants had moderate ectomorphy and mesomorphy components, with low endormorphic values for both male and female runners. Percent body fat by six skinfolds rated the participants as athletic according to norms used in evaluating trained persons (Netfit, 2012). It showed that the runners have low levels of fat, bordering what is referred to as essential fat necessary for vital body functions. Rating of BMI and Waist to Hip Ratio shows similar trend for the athletes. The values are close to those observed by Kong and Heer (2008) who reported low body mass index (20.1 ± 1.8 kg/m^2) and low percentage body fat (5.1 ± 1.6%) among elite Kenyan distance runners.

Table 4.39: Participants' anthropometric values are summarized in Mean and SD for male and female athletes.

VARIABLE		**MALE**		**FEMALE**	
		Mean	SD	Mean	SD
Somatotype (Heath-Carter)	Endomorphy	0.906	0.344	1.840	0.150
	Mesomorphy	3.312	0.917	3.018	0.218
	Ectomorphy	4.803	1.319	4.423	0.496
Body Mass Index (BMI)		18.376	1.624	17.809	0.632
Waist/Hip Ratio (WHR)		0.804	0.025	0.725	0.007
Sum of 6 skinfolds (mm) (Triceps, Subscapula, Supraspinale, Abdomen, Mid thigh and Medial calf)		25.335	5.563	45.1	7.593
%Body fat		5.248	0.585	10.561	1.175

Anthropometric measures such as height and age are used in equations for estimating/predicting spirometric values for various populations (Hankinson, 1999; Stanojevic, 2008). Most of these equations have been derived from measurements data collected from people outside Africa. On the other hand, some studies have reported positive relationships between some spirometric variables and endurance performance (Adegoke & Arogundade, 2002; Fatemi *et al.,* 2012; Pringle *et al.,* 2005). Pearson correlation analyses from in the current study shows significant relationships between subjects' body height (stretch stature) and PEF (r = .741; p = .002), FVC (r = .640; p = .010) and FEV_1 (r = 587; p = .021) (Table 4.40). These are the same spirometric variables (together with VE and Velocity) that had high correlation with rVO_2 at sub-maximal exercise level (Table 4.22). Other spirometric variables (PIF, FEV_1/ FVC, MIP) recorded no significant relationship with subjects' body height ($p > .05$) (Table 4.40).

Table 4.40: Pearson correlation analyses for subjects' body height (stretch stature) vs spirometric variables (n = 15).

Spirometric variables	**Correlation with body height**	
	r	*p*
Peak inspiratory flow (PIF)	.217	.437
Peak expiratory flow (PEF)	.741**	.002
Forced vital capacity (FVC)	.640*	.010
Forced expiratory volume in one second (FEV_1)	.587*	.021
Forced expiratory volume in one second as a proportion of forced vital capacity (FEV_1/ FVC)	.085	.764
Maximum inspiratory pressure (MIP)	.160	.570

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Subjects' body height (stretch stature) recorded high correlation with velocity/speed at maximal exercise level (r = .668; p = .009) and with maximal oxygen consumption relative to body weight (rVO_2 max) (r = .564; p = .029) (Table 4.41). Other anthropometric variables which recorded significant correlation with velocity/speed at maximal exercise level at $p < .01$ are waist to hip ratio (WHR) and percentage body

fat (inversely). Waist girth, sitting height and Troncherterion-tibiale laterale recorded significant positive correlation with velocity/speed at maximal exercise level at $p <$ .01, while sum of skinfolds, and endomorphic component recorded significant inverse correlation at same confident interval. These anthropometric variables also registered significant relationship with maximal oxygen consumption relative to body weight (rVO_2 max), with sitting height recording a stronger association than body height (Table 4.41).

Table 4.41: Correlation analyses for subjects anthropometric variables vs velocity/speed at maximal exercise level and rVO_2 max (n = 14).

Anthropometric variables	**Correlation with velocity/speed**		**Correlation with VO_2**	
	r	*p*	*r*	*p*
Body height (stretch stature)	.668**	.009	.564*	.029
Body weight/mass	.519	.057	.384	.178
Body mas index (BMI)	-.044	.880	-.145	.621
Waist girth	.575*	.031	.313	.276
Arm girth	.183	.530	.093	.751
Gluteal girth (max.)	-.356	.212	-.515	.060
Calf girth (max.)	.162	.580	.019	.948
Waist to hip ratio (WHR)	.739**	.003	.624*	.017
%Body fat	-.713**	.004	-.839**	.000
Sum of 6 skinfolds	-.645*	.013	-.763**	.001
Sum of 8 skinfolds	-.630*	.016	-.760**	.002
Sitting height	.617*	.019	.667**	.009
Troncherterion ht	.452	.105	.295	.305
Troncherterion-tibiale laterale	.568*	.034	.156	.595
Tibiale laterale ht	.405	.150	.321	.263
Tibiale mediale-sphyrion tibiale [cm]	.345	.226	.167	.569
Endomorphy	-.649*	.012	-.726**	.003
Mesomorphy	-.029	.921	-.008	.978
Ectomorphy	.093	.753	.386	.173

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Kong and Heer (2008) reported small calf circumference (34.5 ± 2.3 cm) among Kenyan distance runners and suggested that the slim limbs may positively contribute to performance by having a low moment of inertia and thus requiring less muscular effort in leg swing. The current study similarly observed small calf girth values

(33.17±1.78 cm [male], 31.79±1.19 cm [female]). However, the values showed no correlation with either maximal endurance speed / velocity at maximal exercise level (r = .162; p = .580), maximal oxygen consumption (r = .019; p = .948) (see Table 4.41), or running economy (r = .346; p = .226) (see Table 4.42).

Table 4.42; Pearson correlation analysis between calf girth and running economy (VO_2 at 16/14 km/hr as a percentage of VO_2peak) (n = 14) (p > .05).

		Calf girth (max.) [cm]	VO_2 at 16/14km/hr as a % VO_2peak
Calf girth (max.) [cm]	Pearson Correlation	1	.346
	Sig. (2-tailed)		.226
VO_2 at 16/14 km/hr as a percentage of VO_2peak	Pearson Correlation	.346	1
	Sig. (2-tailed)	.226	

4.9.3. Running Economy and Endurance Performance

Running economy (RE), defined as the energy cost (VO_2) of sub-maximal running, contributes to endurance running performance (Jones, 1998; Noakes, 2001; Saunders *et al.,* 2004). It can discriminate performance capability in athletes of similar/ homogeneous in VO_2 max. Subjects with good running economy can outperform subjects with higher VO_2 max values. Factors involved in the determination of RE include biomechanical factors involved in running style, and physiological such as greater oxidative capacity in endurance trained muscles (including proportion of Type 1 fibers) (Noakes, 2001; Saunders *et al.,* 2004).

Running economy (RE) can be taken as VO_2 for a given sub-maximal speed (Jones, 1998; Noakes, 2001). VO_2 values at 14.0–18.0 km/h (16 km/h and 14 km/h for male and female respectively) have been used as measures of running economy among endurance runners (Jones, 1998; Noakes, 2001; Scholz *et al.,* 2008). Values reported by studies include 52.4 ml/kg/min for elite male runners (Saunders *et al.,* 2004), 48.45±5.69

ml/kg/min for a group of 15 highly trained runners (Scholz *et al.,* 2008), and 53 to 47.6 ml/kg/min have been reported for elite female world marathon champion (Jones, 1998). RE and VO_2 max has been shown to be separately related to endurance running performance. RE (VO_2 for a given sub-maximal speed) expressed as a percentage of VO_2 max (% VO_2 max) has been used to account for individual differences in running economy and VO_2 max in relation to performance, and referred to as the fractional utilization of VO_2 max and/or aerobic running capacity of a runner (Svedenhag, 2001).

The percentage of VO_2 max value expresses the combined effects of VO_2 max and of running economy on performance. High (inverse) correlation has been reported among marathon runners between this measure (% VO_2 max) and performance (race times) (r = -0.94, n = 35) at sub-maximal speed of 15 km/hr (Svedenhag, 2001). In the current study, values of 57.95±2.35 ml/kg/min (for male at 16 km/hr) and 42.18±7.28 ml/kg/min (for female at 14 km/hr) were recorded. When expressed as a percentage of VO_2 max, these values translate to 90.46±6.99 and 84.81±15.20 respectively, and 88.85±9.70 when combined. These values are not superior to reported values for elite runners; 52.4/70.3*100 = 74.54% (Saunders *et al.,* 2004), and for a highly trained world marathon champion; 53/72.8*100 = 72.80% (Jones, 1998).

4.9.4. Ventilatory Threshold and Endurance Performance

Ventilatory Threshold (VT) refers to the point at which there is increased pulmonary ventilation during incremental endurance exercise. It has been found to correspond with lactate threshold (LT), also referred to as anaerobic threshold (AnT) -an exercise point at which blood lactate increases sharply due to anaerobic respiration. LT is a strong predictor of distance running performance (Hoffman, 1999) and the running speed at which it occurs determines the speed that can be sustained during distance running races (Jones, 1998). VT is regarded as a noninvasive way of assessing lactate threshold by

monitoring changes in the pulmonary ventilation and/or gas exchange parameters, with several studies having found high correlations between the two phenomena (but not without controversies) (Hoffman, 1999; Okano *et al.,* 2006).

Jones, (1998) observed that two-component linear regression analysis (i.e. a single threshold model) provides a closer fit to the blood lactate-VO_2 relationship during exercise than does an exponential plus constant model. Other authors suggest two threshold model, the first change corresponding to aerobic threshold and Ventilation threshold1, while the second change corresponds with Anaerobic Threshold1 and Ventilation Threshold2 (Okano *et al.,* 2006; Plowman & Smith, 1997; Robergs, 2001). The validity and reliability of lactate threshold determination by visual inspection, and the use of multistage test protocols with stage durations of three to four minutes and small intensity increments have been confirmed by many studies (Hoffman, 1999; Jones, 1998). The current study used this type of protocol and the VT appear to have occurred at exercise stage 3, where the athletes recorded 54.00±9.57 ml/kg/min (89.72±8.57 %VO_2 max) (see Figure 4.1 and Table 4.43).

Table 4.43: Participants' oxygen consumption (rVO_2) and percentage of maximum oxygen consumption (%VO_2 max) at exercise stages 1 to 5 (Mean±SD) (*n*=14).

Exercise level	Variable	
	rVO_2	%VO_2 max
Exercise stage 1	48.54±11.32	81.98±15.66
Exercise stage 2	52.14±9.22	86.69±9.20
Exercise stage 3	54.00±9.57	89.72±8.57
Exercise stage 4	58.35±7.48	97.42±2.63
Exercise stage 5	59.06±9.08	98.29±3.64

These values are higher than those reported by Hoffman, (1999) and Okano *et al.* (2006) (48.00 ± 01.35 and 45.70±6.46 ml/kg/min [82 and 85±0.03 %VO_2 max] respectively) among trained endurance athletes. This may indicate that the subjects have high VT and/or high tolerance for lactic acid.

CHAPTER FIVE: DISCUSSION

Investigation of pulmonary factors (ventilation, respiratory and arterial blood gases) among middle and long distance runners appreciates the role of oxygen delivery system and carbon dioxide removal in endurance performance. There is considerable literature that show respiratory system as an exercise limiting factor in normal, endurance trained subjects (Amann, 2012; Boutellier, Buchel, Kundert & Spengler, 1992). The study sought to establish the status of this system among Kenyan runners who have dominated this field world over, provoking curiosity and debate among academicians, coaches/trainers, athletes as well as the general public (Noakes, 2001; Onywera et al., 2006; Prommer *et al.,* 2010; Saltin *et al*., 2003; Scott & Pitsiladis, 2007). Studies have focused on various aspects of Kenyan running phenomenon but the jury is not yet made on the key factors that work exclusively or in cohort to determine the performance (Onywera et al., 2006; Pitsiladis *et al.,* 2004).

Effects of high altitude (-living and training at high altitude) has been touted as an essential part of the puzzle. However, while living at high altitude has been shown to be associated with increased hemopoiesis / erythropoietin, training at high altitude has been found to lower VO_2 max and training intensities (Bailey & Davies, 1997; Levine, 2002; Loffredo & Glazer, 2006). Also, other population who live at high altitude areas such as Nepal, Peru, Mexico as well as other African countries are not known to perform as good as the Kenyans in endurance races (Hamilton, 2000). These facts have led to believe that the Kenyan runners (majority of whom come from Kalenjin ethnic group) are genetically endowed for activity of this nature, even though research have not identified the gene/s that is/are responsible for superior performance in endurance races (Scott *et al*., 2005; Scott & Pitsiladis 2007).

High aerobic capacity (high VO_2 max) has been reported among Kenyan runners by several studies (Larsen, 2003; Saltin *et al*., 2003). However, factors that facilitate the high delivery of oxygen to be utilised by the working muscles have not been clearly determined. While VO_2 max has been shown to be an accurate predictor of aerobic performance, the percentage of VO_2 max that can be maintained over time is more indicative of success than the maximal value which cannot be maintained for very long (Warpeha, 2003). Larsen (2003) observe that running at a high fractional VO_2 max and having a good running economy may be the primary factors favouring the good performance of endurance athletes rather than them having a higher VO_2 max than other elite runners. The author says that Kenyan elite runners have used their potential from genetic endowment which gives them favourable body shapes for good running economy to be in the upper range both in regard to VO_2 max and to a high utilization of this capacity during endurance running.

Limitations to aerobic capacity can be experienced at particular phases/ stages of the oxygen delivery link -from the air to the lungs, from alveolar space to arterial blood, from arterial blood to the tissues, as well as in cellular respiration. Spirometric measures have been used to evaluate the status of lung capacity and the concomitant effects on external and internal respiration in human (O'Donnell, Lam & Webb, 1999; Stanojevic *et al.,* 2008). In exercise, some studies have shown high correlation of some spirometric measures and performance in endurance events (Adegoke & Arogundade, 2002; Fatemi *et al.,* 2012; Pringle *et al.,* 2005), while some have shown weak or no significant relationships (Amonette & Dupler, 2002; Knechtle & Kohler, 2008).

Spirometry results in the current study suggest that most ventilation parameters of Kenyan runners are comparable with those of general population (see tables 4.6, 4.7

and 4.8). Prediction equations from the National Health and Nutrition Examination Survey (NHANES III) for African American were used as presented by Hankinson *et al.* (1999) (Appendix III). These equations have been widely used, especially where there are no locally established norms. According to Mackenzie (2004), Caucasians have the largest FEV_1 and FVC, and Polynesians are among those with lowest. The values for people of African origin are 10 to 15% lower than for Caucasians of similar age, sex and height because for a given standing height their thorax is shorter. Chinese have been found to have an FVC about 20% lower and Indians about 10% lower than matched Caucasians. There is little difference in PEF between ethnic groups (Mackenzie, 2004). Given that most spirometric values of Kenyan runners are comparable to those of general population and yet they are able to cope with demands of high oxygen delivery, it is logical to say that they may be enjoying enhanced gaseous exchange status. However, this requires more studies utilising larger sample size to be confirmed. This study agrees with recommendations by Orie (1999) that there is need to establish local norms in order to make more accurate health diagnosis and decisions.

Some spirometric variables (FVC, FEV_1 and VE) recorded significant Pearson correlation with performance indicators, more so during the sub-maximal running (see Table 4.22). Some other studies have shown correlation between some spirometric measures and VO_2 max (Fatemi *et al.,* 2012; Pringle *et al.,* 2005). However, it is the sub-maximal VO_2 which determines the performance in an endurance race than the VO_2 max (Larsen, 2003). Therefore, correlating variables with sub-maximal VO_2 is more relevant than with VO_2 max. The current study data is in agreement with this fact, with the running speed recording significant correlation with sub-maximal VO_2 and no correlation with VO_2 max (see Table 4.22). Although these variables can be

said to be predictors of endurance running performance indices (sub-maximal VO_2 and sub-maximal speed), they should be considered in cohort with other factor/s which may not have been exposed by this study. Caution need to be exercised in the same since correlative evidence does not mean causation. Sitting height may be related to larger lungs, thus FVC which makes it correlate highly with VO_2 (r = .667; p = .009) and running speed (r = .617; p = .019) (Table 4.41). Troncherterion height recorded no significant association. This may relate to observations by Mackenzie (2004) that the values of FEV_1 and FVC, for people of African origin are 10 to 15% lower than for Caucasians of similar age, sex and height, and that for a given standing height their thorax is shorter. This is because a person with more sitting height has a taller thorax, and hence larger lungs.

Incremental treadmill exercise is routinely used to mimic endurance running in studies of this nature. Similar approach was taken by the current study, with athletes being encouraged to push themselves to attain maximum effort. Respiratory exchange ratio (RER) of 1.00±.07 and 1.02±.07 were reached in this study (see tables 4.11 and 4.12), at exercise stage 4/sub-maximal and exercise stage 5/maximal respectively. According to Haff & Dumke (2012), and Plowman and Smith (1997), RER equal or greater than 1.0 indicates (is a criterion for determining) that the tests were truly maximal. Increased intensity of the exercise as one approaches maximal level produces lactic acid which takes up bicarbonate ions to make carbonic acid, which in turn dissociates to water and carbon dioxide (Haff & Dumke, 2012). To avoid accumulation of these metabolites and the ensuing metabolic acidosis, the increasing carbon dioxide has to be eliminated through increased ventilation. Results of respiratory data analysis in the current study showed that Vt and Fb increased only marginally between sub-maximal and maximal stages, but the combined effects

increases VE significantly (see Table 4.14). ABG data analysis showed that carbon dioxide was adequately removed from blood and that there was partial compensation by respiratory system, both at sub-maximal and maximal exercise (section 4.6.1, tables 4.25 and 4.26). These may point to adequate ventilatory responses which can be able to support relatively high intensity endurance exercise.

Highest breathing frequency (Fb) values recorded during exercise were significantly higher than breathing frequency at maximal exercise (see tables 4.15 and 4.18c) and no significant difference between sub-maximal and maximal values (tables 4.14 and 4.18b). This may indicate some potential which can be tapped for better performance in endurance exercise through training. Plowman and Smith (1997) observe that tidal volume (Vt) increases with exercise up to moderate intensity after which it may plateau or decrease. Any further increase in ventilation towards maximal exercise is achieved through an increase in breathing frequency (Fb). It is logical to say that practicing using proportion of maximum voluntary ventilation (which involves deep and fast breathing) for a few minutes (or using commercially produced inspiratory muscle training devices) in endurance training programmes, may enhance Fb to match higher pace and rhythm of running, and probably lead to more complete respiratory compensation for metabolic acidosis. This is in concurrence with the findings by Pringle *et al.* (2005) that maximum voluntary ventilation (MVV) explained high proportion of variance in distance running performance. It is possible however, that more ventilation would have lowered level of CO_2 and result to alkaline status, but it could also offset the overall acidosis status of the arterial blood caused by metabolic processes associated with the high intense work in the muscle tissues, allowing the runner to achieve higher intensity/speed.

The physiological sequence of ventilatory responses to exercise is not fully understood as yet. Oxygen, carbon dioxide and pH receptors are said to be the primary initiators as they are stimulated by the changing levels of the respective elements in the blood (Plowman & Smith, 1997; West, 2008). However, during exercise ventilation adjusts before changes in oxygen, carbon dioxide and/or pH reach a magnitude that can increase ventilation. Only at severe exercises levels that changes in these parameters are noticeable in the arterial blood (Graaff & Fox, 1995). The results of the current study seem to agree with this observation in that $PaCO_2$ remained within normal range (and even dropped low during the sub maximal and maximal exercise) (tables 4.23, 4.25 and 4.26) as minute ventilation (VE) increased (tables 4.11 and 4.12). Graaff and Fox (1995) observe that exercise hyperpnea (increase in pulmonary ventilation during exercise) is ordinarily enough to prevent marked changes in the composition of arterial blood. The author suggests that neurogenic and chemical mechanism may be involved in hyperpnea –which is different from hyperventilation as $PaCO_2$ remains within normal range. This agrees with Landau (1980) who notes that carbon dioxide is lost in the lungs, and therefore no signals to be detected by arterial chemoreceptors. The author cites the possible causes of exercise hyperpnea as including; reflexes from moving limbs, increased temperature, action of epinephrine, and cortical (psychic) influences.

From the results of the current study, indications are that perhaps the most important respiratory factor in Kenyan elite running is the ability to maintain / sustain relatively high sub-maximal VO_2 for long period and the corresponding relatively high speed, rather than the absolute VO_2 max. This is indicated by the fact that there is no significant difference between VO_2 at penultimate stage /sub-maximal stage 4 and maximal stage 5 (p = .427) (tables 4.14, 4.21b and 4.21c), while the level of acidosis

is significantly lower at high sub-maximal level / stage 4 than at maximal level stage 5 (p = .020) (tables 4.28, 4.31b and 4.31c). These indicate that the speed/intensity associated with the relatively high VO_2 can be sustained given the less acidic internal environment. This is in agreement with other studies which have reported high lactic acid tolerance at high VO_2 max among Kenyan runners (Larsen, 2003; Tam *et al.,* 2012). It is also in line with observations by Mackenzie (2010) that VO_2 max on its own is a poor predictor of performance but using the velocity and duration that an athlete can operate at their VO_2 max provides better indication of performance. The less acidic internal environment in exercising athlete is majorly maintained by respiratory system (renal system being the other, is slow). This indicates that ventilatory responses in Kenyan runners were able to largely offset (reduce) the metabolic acidosis resulting from the high sub-maximal intensity work in the muscle tissues. Favourable enzymatic activity in the active muscles can also be responsible for sustaining high VO_2 max by ensuring low lactic acid accumulation as reported by Weston *et al.* (1999), but studies comparing the response to training of Kenyans and Caucasians have shown similar trainability with respect to oxidative enzymes (Larsen, 2003; Saltin *et al.,* 1995a).

Possible explanation of high sub-maximal VO_2 and VO_2 max in Kenyan runners could also be more effective blood supply as indicated by relatively low % HR Max during exercise compared to predicted values (Table 4.38). Efficiency of blood supply may be facilitated by higher stroke volume and higher capillarisation. Higher stroke volume without capillarisation would result to faster transit time of blood through pulmonary circulation, resulting to reduced time for gaseous exchange. This could worsen during exercise if there are shunts which would allow higher volume of blood to pass through the lungs without gaseous exchange taking place (Stickland *et al.,*

2004). Dempsey *et al.* (2008) and Nielsen (2003) observes that a widening of the PAO_2 to PaO_2 difference does indicate a diffusion limitation attributable to a ventilation–perfusion mismatch which affects the transportation of O_2 from alveoli to the pulmonary capillaries, and/or shunts (intra-cardiac or intra-pulmonary). These lead to some deoxygenated mixed venous blood getting back to circulation. The authors note that with the marked increase in cardiac output during high intensity exercise, diffusion limitation is aggravated by the fast transit time and compounds the O_2 transport problem. Higher stroke volume (as opposed to high heart rate) coupled with higher systemic and pulmonary capillarisation and less (or absence of) pulmonary shunts can therefore ensure more efficient blood circulation and gaseous exchange (less exercise-induced arterial hypoxemia) during exercise. The relatively low HR (low %MHR) at all exercise intensities in the current study (Table 4.38 and Figure 4.12) may be indicative of the above circumstances being present in the subjects. This is line with Saltin (2003) who reported higher muscle capillarisation compared to Scandinavian runners.

EIAH can be experienced at mild, moderate and severe levels which correspond to an absolute SaO_2 values of 93–95%, 88–93% and <88% respectively, and A-aDO_2 > 24 mmHg (Dempsey & Wagner, 1999). Only moderate level of EIAH was recorded in the current study (SaO_2 = 89.53±4.68 and 92.07±1.69 [%]; A-aDO_2 = 24.29±4.80 and 19.70±11.01 [mmHg] for male and female respectively) during maximal endurance exercise (see Table 4.26). This could indicate favourable gaseous exchange status which can enhance performance. Amann *et al.* (2007) observed that across the range of normoxia to severe hypoxia, the major determinants of exercise performance switches from a predominantly peripheral origin of fatigue to a hypoxia-sensitive central component of fatigue. The difference in effects on endurance running

performance between moderate and severe hypoxemia need to be determined among runners of different ethnic origin.

It is logical to say that the status of the difference between sub-maximal, peak and maximal values can give an indication of the importance of the variable as a limiting factor to endurance performance. The significant difference between sub-maximal and maximal values would mean that critical values/thresholds were triggered off by the last exercise stage and the body could not continue. In this case, HCO_3, A-aDO_2, pH and tHb would appear to more important as limiting factors than SaO_2, PaO_2, PAO_2, CaO_2 and $PaCO_2$, as far as ABG variables are concerned. PaO_2 and PAO_2 changed only marginally between sub-maximal and maximal, but cumulative effects changed A-aDO_2 significantly. Although A-aDO_2 recorded significant difference between sub-maximal and maximal levels, the value exceeds normal range only marginally.

Total hemoglobin (tHb) increased significantly between sub-maximal and maximal exercise (p = .030) (tables 4.28, 4.35b and 4.35c), while arterial oxygen content (CaO_2) is not altered significantly during these exercise stages (p = .265) (tables 4.36b and 4.36c). The normal ranges for haemoglobin depend on the age and, beginning in adolescence, the sex of the person. The normal ranges are: Adult males; 14-18 gm/dl, Adult women; 12-16 gm/dl (Billett, 1990). Total haemoglobin (tHb) increases with increasing exercise intensity. This may be due to decrease in blood volume as a result of fluid shifts and fluid loss. According to Plowman and Smith (1997), blood volume decreases during dynamic aerobic exercise mainly as a result of fluid shifts and to a lesser extent due to fluid loss. The author observes that the magnitude of the decrease in plasma volume is dependent upon the intensity of exercise, environmental factors,

and the hydration status of the individual. With the results of the current study, it is logical to conclude that higher metabolites/acidosis (associated with high exercise intensities/ stage 5) in the working tissues attracted more fluid from the blood vessels. This would consequently reduce blood in circulation and hence the effectiveness of gaseous exchange. In this case, the metabolites which cause acidosis resulting to tissue fluid shift (associated with the significant increase in tHb values) and the rate of their removal can be said to be critical limiting factor to endurance performance.

$PaCO_2$ seems to be less a limiting factor, as it remains low i.e. does not rise sharply/ is not elevated at maximal exercise. Compensation for metabolic acidosis is almost complete at sub-maximal exercise (pH = 7.33±.08[Male], 7.33±.01[Female], 7.33±.07[Total]) (see section 4.6.1, tables 4.25 and 4.26), which may enables to sustain relatively high sub-maximal VO_2 with the resulting relatively less acidic tissue environment. This indicates adequate/sufficient ventilation at sub-maximal exercise stage. It is debatable whether Fb could achieve more compensation if it increased with higher intensity. It can be argued that more ventilation could have led to alkalinity $PaCO_2$ status. However, as the exercise intensity increases, the body produces more carbon dioxide from buffered lactate (Haff & Dumke, 2012), thus RER > 1.0. This extra (non-metabolic) CO_2 need to be removed via increased ventilation. Also, $PaCO_2$ was still several mmHg before reaching alkalinity (30mmHg at the study site altitude).

Perhaps the most critical limiting factor in endurance running is bicarbonate ions (HCO_3) (or variable/s associated with it) with the variable showing the most consistent tread -decreasing with increasing exercise intensity (Figure 4.7 and tables 32a-g). The effect size for this variable is the highest among all the test variables (Eta Sqd. = .724) (section 4.7.3 and Table 4.32e). It is lowest with maximal exercise, and

correspondingly high at low exercise intensities. Its level is reduced by buffering lactic acid from anaerobic respiration in high intensity exercise (Plowman & Smith, 1997; Robergs, 2002), and this indicates reduced VO_2 efficiency. It has been demonstrated that ingestion of sodium bicarbonate increases pH (alleviate acidosis) at rest and during sub-maximal and maximal endurance exercise (Nielsen *et al.,* 2002; Price, Moss and Rance, 2003). Sports drinks with HCO_3 boosting effect in later stages of road races can therefore be appropriate as ergogenic aid (at refreshment points) in endurance running. This is in agreement with Nielsen *et al.,* (2002) who observed that the enlarged blood-buffering capacity after infusion of bicarbonate attenuated acidosis and in turn arterial desaturation during maximal endurance exercise.

There is indication of high VT and tolerance for lactic acid/ blood lactate by the subjects, given that the VT appears to have occurred 2 stages prior to the terminal stage of the exercise test. The VT is identified through the changes in the pulmonary ventilation, as well as of the ventilator equivalent of the O_2 and CO_2 (Okano *et al.,* 2006; Robergs, 2001). Okano *et al.* (2006) reported similar VO_2, Work rate, and HR values for the anaerobic threshold (IAT) and the ventilation threshold (VT) with high and significant associations, and recommended the adoption of the VT because it is a non-invasive method to determine the anaerobic threshold in endurance athletes. Well-trained subjects are able to reach high work load levels before this clear break in linear VE increase (West, 2008). Values of 048.00 ± 01.35 and 45.70±6.46 ml/kg/min (82 and 85±3 %VO_2 max) have been reported among trained endurance athletes (Hoffman, 1999; Okano *et al.,* 2006). In the current study, the VT appears to have occurred at exercise stage 3, with the athletes recording 54.00±9.57 ml/kg/min (89.72±8.57 %VO_2 max) (Figure 4.1 and Tables 4.43). This may indicate that the subjects had high VT and high tolerance for lactic acid / blood lactate since they were

able to accomplish another higher intensity exercise stage before getting into their maximal exercise stage.

The current study does not identify a single factor that is responsible for success of Kenyan runners but gives some insight into pulmonary factors that may work in cohort with others to favour better endurance performance. It agrees with Joyner and Coyle (2008), and Noakes (2001) who asserts that elite athletic performance involves integration many factors that function cooperatively to efficiently transfer the energy from aerobic and anaerobic ATP turnover into velocity and power. The authors note that the challenge for physiologist is in establishing the relative importance of the different variables involved, with Joyner and Coyle (2008) adding that complex motivational and sociological factors also play important roles in determining success of athletes. It is worth noting that the performance indicators (VO_2 and running speeds at VO_2 max) in the current study were reached while running at moderate altitude (1,661m [5,450ft] above sea level). Therefore, the athletes would record higher performance indices at low altitude / sea level. In addition, some athletes were not used to running on treadmill. With some Kenyan known to win international races while running bare foot, the subjects can be expected to score higher when running on track (where they are used to), and with greater motivation such as financial rewards that goes with winning major competitions, than on treadmill.

CHAPTER SIX: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1. Introduction

This section presents a summary of the study, conclusions made, recommendations for policy and practice, as well as recommendations for further research.

6.2. Summary

The study sought to find out if Kenyan distance runners have enhanced pulmonary function which would lead to enhance oxygen delivery and/or removal of carbon dioxide for better endurance performance. It was postulated that favourable spirometric, ventilatory and gaseous exchange parameters may reduce or ease (attenuate) pulmonary limitations to endurance performance such as EIAH, excessive A-aDO_2 and metabolic acidosis.

The study adopted an experimental design involving spirometric assessments and incremental treadmill running tests to maximal effort. Fifteen (10 male, 5 female) purposively selected elite Kenyan runners performed baseline spirometry and a graded treadmill test to exhaustion. Respiratory measures obtained during treadmill test included tidal volume (Vt), breathing frequency (Fb), minute ventilation (VE), oxygen consumption (VO_2), carbon dioxide production (VCO_2) and respiratory exchange ratio (RER). Arterial blood gas (ABG) data (SaO_2, PaO_2, $PaCO_2$, A-aDO_2, and pH) were collected from samples obtained from athletes via indwelling cannula.

The findings indicated that there was no significant difference between most spirometric values and the predicted values for male runners. A few of the variables (PEF, FVC, and FEV_1) values however rated lower than predicted in female runners. For the exercising respiratory variables, oxygen consumption relative to body weight

(rVO_2) at sub-maximal and maximal exercise stages rated excellent and superior on the table of established norms.

The results of ABG indicate that Kenyan elite distance runners experienced moderate metabolic acidosis during sub-maximal (pH = 7.33±.07, $PaCO_2$ = 34.19±4.77 mmHg and HCO_3 = 18.91±2.96 mmol/L) and maximal endurance exercise (pH = 7.31±.08, $PaCO_2$ = 34.15±3.44 mmHg and HCO_3 = 17.80±3.03 mmol/L). They experienced sufficient hyperventilation (hyperpnea) to keep $PaCO_2$ within normal range, and to partially compensate for metabolic acidosis during sub-maximal and maximal endurance exercise. The results also showed that the runners only experienced moderate level of exercise-induced arterial hypoxemia during sub-maximal endurance exercise (SaO_2 = 91.12±4.27[male], 92.73±2.65[female] %), and maximal endurance exercise (SaO_2 = 89.53±4.68[male], 92.07±1.69[female] %). They did not suffer excessive alveolar to arterial oxygen difference beyond normal levels (< 24 mmHg) during sub-maximal ($A\text{-}aDO_2$ = 22.49±4.53[male], 16.86±8.13[female] mmHg) and maximal ($A\text{-}aDO_2$ = 24.29±4.80[male], 19.70±11.01[female] mmHg) endurance exercise.

Some pulmonary function parameters were found to have significant correlation with indicators of performance (high sub-maximal speed and VO_2) during sub-maximal endurance exercise (PEF [r = .625, p = .017], FVC [r = .741, p = .002], FEV_1 [r = .658, p = .010] and VE [r = .792, p = .001], Speed [r =.670, p = .009] with sub-maximal VO_2). Other parameters (PIF, FEV_1/FVC, MIP, Vt, %MHR, RER and ABG) had lower or no correlation with sub-maximal VO_2 and speed, especially at maximal endurance exercise. FVC and VE had significant correlation with rVO_2 both at sub-maximal and maximal levels, but stepwise regression showed that only VE was a

significant predictor of rVO_2 at sub-maximal exercise level. Ventilation threshold (VT) occurred at higher percentage of VO_2 max (89.72±8.57 %VO_2 max) than values reported for Caucasian runners.

6.3. Conclusions

From the findings of the study the researcher concludes that Kenyan distance runners' spirometric values are comparable to values predicted by commonly used equations. However there is need to establish local norms for more accurate interpretations of these data. Significant correlation exists between some spirometric variables and sub-maximal endurance running performance. Ventilatory responses of Kenyan runners are able to support relatively high intensity endurance performance through both increased breathing and tidal volume. Breathing frequency however indicates some potential which may be tapped for better performance in endurance exercise through training. Oxygen consumption (rVO_2) rated excellent and superior against commonly used norms. There is relatively high rate of oxygen consumption which can be sustained, given that sub-maximal value of rVO_2 do not differ significantly from maximal value (p = .739). The subjects had high VT which may indicate low rate of blood lactate accumulation, and high tolerance for lactic acid since they were able to accomplish another higher intensity exercise stage before getting into their maximal exercise stage.

Regarding ABG values, Kenyan distance runners experience only moderate levels of exercise-induced arterial hypoxemia ($SaO_2 \geq 89\%$ and A-a$DO_2 < 24$ mmHg). Oxygen content in arterial blood does not change significantly (remains relatively the same) through different stages of incremental endurance exercise. Carbon dioxide was adequately removed from blood and there was partial compensation by respiratory

system for metabolic acidosis, both during sub-maximal and maximal endurance exercise. These may mean that there are adequate ventilatory responses which can be able to support relatively high intensity endurance performance. The most critical / limiting factor in endurance performance among Kenyan runners is HCO_3 (and/or associated factors) which showed most consistent decrease with increasing endurance exercise intensities across the participants, and largest effect size (Eta Sqd. = .724). Kenyan endurance runners utilised relatively low percentage of their maximum heart rate during sub-maximal and maximal endurance exercise. This must have been accompanied by large stroke volume. The runners' somatotype mainly consists of moderate ectomorph and mesomorph with low endomorph components.

In summary, most baseline pulmonary function values of Kenyan distance runners are comparable to values predicted by commonly used equations. However, their pulmonary function is able to support delivery demands of superior oxygen consumption at sub-maximal and maximal endurance exercise. The runners seem not to be severely affected by exercise-induced arterial hypoxemia during sub-maximal and maximal endurance exercise. This may point to enhanced gaseous exchange status such as more pulmonary capillarisation and / or less shunts.

6.4. Recommendations for Policy and Practice

Given that parameters associated with acidosis proved to be critical factors that influence performance in endurance exercise, the study recommends that possible ways through which the status is alleviated are considered during training and competitions. Use of sports drinks with HCO_3 boosting effect in later stages of endurance events as an appropriate ergogenic aid is a potential strategy. This is due to its buffer effects which obviate excessive acidosis, ensuring optimal metabolic

processes at higher endurance exercise intensities. It can be given at refreshment points during road races, or taken within a short duration prior to a long or middle distance races, or other endurance sports. Respiratory training sessions also has potential to improve compensation for metabolic acidosis and thus allow for higher intensity exercise to be achieved.

6.5. Recommendations for Further Research

More studies need to be done in this area to determine the extent pulmonary functions of Kenyan distance runners compares to and differs from those of runners from other regions, and the effects on endurance race performances. The difference in effects on endurance running performance between moderate and severe hypoxemia need to be quantified among runners of different ethnic origin. Studies should also be done to investigate the difference in shunts among athletes of different ethnic origin and the effects on performance. Telemetric respiratory and metabolic systems should be used in future studies of this nature so as to capture the data during actual running activity in the track. It could be possible that the runners can push themselves harder i.e. attain higher speed as well as sub-maximal and maximal VO_2 on the field where they are used to, as compared to running on treadmill where they are not accustomed. Researchers should also investigate whether respiratory training sessions such as practicing using proportion of maximum voluntary ventilation for a few minutes (or using commercially produced inspiratory muscle training devices) in their endurance training programmes can increase breathing frequency to match and support higher endurance running pace.

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APPENDICES

8.1. Appendix I; Participant Information and Consent Form

RESEARCHER/ INVESTIGATOR, SUPERVISORS & THEIR CONTACT:

Francis Mundia Mwangi, Ph.D. Student,
Dept. of Recreation Management & Exercise Science,
Kenyatta University,
P O Box 43844 00100 Nairobi, Kenya.
Email: framwa@gmail.com.com
Cell phone: +254-722761379 (available 24hrs a day)

Vincent Onywera, Ph.D.
Department of Recreation Management and Exercise Science,
Kenyatta University,
P O Box 43844 00100 Nairobi, Kenya.
Email: vonywera@gmail.com
Cell phone: +254-721813114
Office: +254-02-801901 Ext 57284

Michael Boit, Ph.D.
Department of Recreation Management and Exercise Science,
Kenyatta University,
P O Box 43844 00100 Nairobi, Kenya.
Email: mikeboit@yahoo.com
Cell phone: +254-722794167
Office: +254-02-801901 Ext 57284

William Sheel, Ph.D.
School of Human Kinetics,
University of British Columbia,
6108 Thunderbird Blvd, Vancouver, BC, Canada V6T 1Z3
Email: bill.sheel@ubc.ca
Tel: +1.604.822.4459
Fax: 604/822-9451

INTRODUCTION: You are being invited to participate in this study because you are an elite internationally ranked Kenyan runner between the age of 18 and 40. If you regularly use medications, have a medical history of cardiovascular (eg. Hypertension, cardiac arrthymias) and respiratory disease (eg. Asthma) you are ineligible to participate in this study.

YOUR PARTICIPATION IS VOLUNTARY: Your participation is entirely voluntary, it is important for you to understand what the research involves. This consent form will tell you about the study, why the research is being done, what will happen to you during the study and the possible benefits, risks and discomforts. If you wish to participate, you will be asked to sign this form. If you do decide to take part in this study, you are still free to withdraw at any time and without providing any reasons for your decision. Please take the time to read the following information carefully and to discuss it with your family, friends and doctor before you decide.

WHO IS CONDUCTING THE STUDY? The study is being conducted by a joint collaboration between researchers within the Department of Recreation Management and Exercise Science at Kenyatta University in Nairobi, Kenya, and researchers within the School of Human Kinetics at the University of British Columbia in Vancouver, Canada.

BACKGROUND: In the past 3-4 decades athletes from East Africa have dominated international running events. This is especially the case for runners of Kenyan ancestry. For example, excluding the two Olympics boycotted by Kenya, Kenyan athletes have not lost the steeplechase event since 1968. Moreover, runners from this East African nation account for 91 of the 100 best times ever in the steeplechase (IAAF all time list). Why do Kenyans and other East African athletes perform so extraordinarily well in endurance races? The goal of this research is to answer this question by studying the best runners in the world in Kenya in collaboration with Kenyan researchers.

From previous research studies it is known that elite runners have an extremely high ability to use oxygen during exercise. We are interested in how it is that oxygen gets from the air to the blood so muscles can use it during exercise. Many elite athletes become limited by their pulmonary system such that the difference in oxygen between the air in the lungs and the air in the blood is widened, hyperventilation is inadequate, and metabolic acidosis occurs. Further, athletes may become limited by highly fatiguing levels of respiratory muscle work. The effect of this is that blood flow to working muscles in the leg for example is diverted to the working respiratory muscles thereby limiting exercise performance. It is not known if Kenyan elite runners experience these same pulmonary limitations to exercise.

PURPOSE: The purpose of the current investigation is to determine if the best runners in the world have an enhanced ability to transfer oxygen from air to the blood.

WHAT DOES THE STUDY INVOLVE? If you consent to participate in this study, you will be asked to come into the laboratory on three different occasions where physiological measurements will be collected. Ventilation and ventilated gases (oxygen and carbon dioxide) will be assessed by qualified personnel and equipment and monitored continuously. Beat-by-beat blood pressure will be obtained by a cuff fitted around your arm and finger. Heart rate data will be collected continuously using a three lead electrocardiogram system. Oxygen saturation of haemoglobin will be monitored non-invasively via finger or earlobe oximetry. Arterial blood samples will be taken from radial artery via a single percutaneous needle puncture or from an indwelling tube. The experimental session on each day will last approximately 4 hours.

Participants will first fill out several questionnaires that document your ancestry, general health, and your running history. You will then be asked to conduct several breathing maneuvers, which is collectively called spirometry. These maneuvers allow us to assess your lung function and lung volumes. During these tests you will be asked to breathe on a mouthpiece and take large forceful breaths. After spirometry has been conducted you will then be asked to rest quietly for 10-15 minutes to ensure stable baseline recordings. Then we will ask you to exercise on a treadmill. During the treadmill test the speed and grade of the treadmill will gradually increase until you are unable to continue. Throughout the test you will be breathing on a mouthpiece so that we can measure the amount of air you are moving in and out of your lungs and so that we can measure the amount of carbon dioxide and oxygen in the air. We will determine your heart rate throughout the exercise test from surface electrode pads that are placed onto your chest with adhesive tape. Arterial blood samples will be taken from radial artery at rest, sub-maximal and maximal exercise levels via a single percutaneous needle puncture (within 15 seconds of the exercise stage), or from an indwelling arterial cannula. This will be done by an authorised trained practitioner (physician), to provide blood specimens for direct measurement of partial pressures of carbon dioxide ($PaCO_2$) and oxygen (PaO_2), hydrogen ion activity (pH), total hemoglobin (tHb) and

bicarbonate ions. After the exercise test you will be able to rest while we remove all instruments from you.
Two days later you will return to conduct two other procedures. The first is referred to as a hypoxic ventilatory response test. During this test you will rest quietly in a semi-seated position and you will breathe on a mouthpiece. We will gradually reduce the amount of oxygen in the air that you are breathing over a 10-minute period. At the end of this test you will notice yourself breathing much more than you would normally be breathing. This is because the lack of oxygen in the air is causing your body to increase is breathing rate. This test is safe and you will not experience any side effects from this test except some people may suffer a temporary mild headache. The next test you will partake in is another exercise test like the test you conducted on the first day except in this case you will breathe a gas mixture with added oxygen. This is done so that we can simulate what exercise would be like if you were exercising at sea level. On Day 3 a treadmill test to exhaustion with induced respiratory muscle fatigue will be done. The participants will perform deep and fast breathing exercise for 15 minutes before taking the treadmill test. This will assess how the work of breathing affects endurance performance.
All tests and data collection will take place at Kenyatta University within the Department of Exercise, Recreation and Sport Science.

WHAT ARE THE POSSIBLE HARMS AND SIDE EFFECTS OF PARTICIPATING? Minimal risks are associated with this study. You may find the measurement of the hypoxic ventilatory response to be uncomfortable. This is only because we have stimulated an increase in the rate and depth of breathing. This is a safe procedure. There also exists the possibility of potential risks from the maximal exercise test, such as vomiting (5%), abnormal blood pressure (<1%), fainting (<1%), disorders of the heartbeat (<0.1%), and very rare instances of heart attack (<0.001%). We will ask you to fill out a Physical Activity Readiness Questionnaire (PAR-Q) to minimize these risks. In the event that such complications occur you would be immediately treated by our attending physician.

It must be noted that individual responses to the experimental procedures exist and you are encouraged to report any unusual sensations or symptoms to the investigator. You are permitted to end testing at any time for any reason. If you do experience undesirable symptoms during the experiment, immediate care will be provided. All procedures used to collect physiological data will pose no risk to your continued health and well-being. These procedures have been performed around the world since the 1960's. You do not have to provide any reason should you wish to withdraw from this study.

WHAT ARE THE SAFTY PRECAUTIONS IN PLACE DURING THE STUDY?
An independent project doctor (Dr. Charles O. Ashira) will be in attendance during the testing period. He is a Senior Medical Officer Registered with Kenya Medical and Dentistry Board. A defibrillator and airway support devices will be available during the study. These are standard items for these kinds of physiology tests. Arrangements will also be made with Kenyatta University Health Unit for emergency admission in the unlikely case of emergencies.
WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY? You may not benefit personally from participation in this study. Your participation in this experiment will contribute an understanding to exercise respiratory physiology in athletes performing at the highest end of the spectrum. This may help improve methods in endurance training. You will however receive an honorarium for your time in this study. This will be equal to $50 USD per experimental day.

CONFIDENTIALITY: Your confidentiality will be respected. Your name will not be used in any publication related to this research, and you will only be identified by subject code. Research records identifying you will be kept for a number of years after the experiment is completed, for publication and ethical reference only. Representatives from Ministry of

Health or Higher Education, Kenya, Canada, or UBC or KU Research Ethics Committee may inspect these records. Records identifying you by name or initial will not be permitted to leave the principal investigator's office, or be copied in any way. However, you should know that because you are an internationally ranked athlete it may be possible to identify you based on your competitive running times. It may be necessary for us to publish these running times to characterize the ability's of the athletes that we have studied.

Please note that you may ask questions at any time. We will be glad to discuss your results with you when they have become available and we welcome your comments and suggestions. If you have any concerns about your rights as a research subject and/or your experiences while participating in this study, contact the Research Participants Information by calling +254-02-810-901 ext.57284.

A trained research assistant will be available on every occasion to explain the procedure and answer any questions. The research team has undertaken these measures (previously without complications) in many individuals of your age.

COMPENSATION AND INJURY: Signing this consent form in no way limits your legal rights against the sponsor, investigators, or anyone else.

CONSENT: In signing this form you are consenting to participate in this research project. Furthermore, signing this consent form in no way limits your legal rights against the sponsor, investigators, or anyone else.

DECLARATION

I understand the purpose and procedures of this study as described and I voluntarily agree to participate. I understand that at any time during the investigation I will be free to withdraw without jeopardizing any medical management, employment or educational opportunities. I have received all pages of the consent form and understand the contents of these pages, the proposed procedures and possible risks. I have had the opportunity to ask questions and have received satisfactory answers to all inquiries regarding this study. I have been told I will receive a signed and dated copy of the consent form.

_____	_____	_____	_____
Signature of Subject	Printed name	Contact	Date
_____	_____	_____	_____
Signature of Witness	Printed name	Contact	Date
_____	_____	_____	_____
Signature of Investigator	Printed name	Contact	Date

8.2. Appendix II; Study Questionnaire

General Information
Today's Date: .....
Name: .....
Date of Birth: .....
Age: .....years.
Height: .....cm.
Weight: .....kg.
BMI: .....
Waist Circumference: .....cm
What is your nationality? .....
Your parent's nationality? .....
Your Grandparent's nationality? .....
Present Medical History

1. Has a doctor ever said that your blood pressure was too high or too low? YES..... NO.....
2. Do you ever have pain in your heart or chest? YES..... NO.....
3. Are you often bothered by a thumping of the heart? YES..... NO.....
4. Does your heart often race fast? YES..... NO.....
5. Do you ever notice extra heart beats or skipped beats?YES..... NO.....
6. Are your ankles or feet often badly swollen? YES..... NO.....
7. Do cold hands or feet often trouble you even in hot weather? YES..... NO.....
8. Do you suffer from frequent cramps in your legs? YES..... NO.....
9. Do you often have difficulty breathing? YES..... NO.....
10. Do you get out of breath long before anyone else? YES..... NO.....
11. Has a doctor ever told you that your cholesterol level was high? YES..... NO.....

If you answered yes to any above questions please explain here:
.....
Do you now have (or have you ever had) any of the following:

12. A chronic, recurrent, or morning cough? YES..... NO.....
13. Any episode of coughing up blood? YES..... NO.....
14. Increased anxiety or depression? YES..... NO.....
15. Problems with recurrent fatigue, trouble sleeping, or increased irritability? YES..... NO.....
16. Migraine or recurrent headaches? YES..... NO.....
17. Swollen or painful knees or ankles? YES..... NO.....
18. Swollen, stiff, or painful joints? YES..... NO.....
19. Pain in your legs after walking short distances? YES..... NO.....
20. Back Pain? YES..... NO.....
21. Kidney problems such as passing stones, burning, increased frequency of urination, decreased force stream, or difficulty in starting or stopping of your stream? YES..... NO.....
22. Any significant vision or hearing problems? YES..... NO.....
23. Any condition limiting the motion of your joints, or any part of your body which could be aggravated by exercise? YES..... NO.....
24. Any recent change in a wart or mole? YES..... NO.....

25. Glaucoma or increased pressure in the eyes? YES..... NO.....
26. Exposure to loud noises for long periods of time? YES..... NO.....

If you answered yes to any above questions please explain here:
.....

Cardiovascular Disease Risk Factors:
27. Do you have high blood pressure? YES..... NO.....
28. If so, are you taking medication to control it? What are you taking?
YES..... NO.....
29. Do you have diabetes? YES..... NO.....
30. If so, are you taking medication to control it? What are you taking?
YES..... NO.....
31. Do you have high blood sugar? YES..... NO.....
32. If so, are you taking medication to control it? What are you taking?
YES..... NO.....
33. What would you consider to be your present level of emotional stress at work, home, or in your personal life?
Very stressed
Occasionally stressed
Rarely stressed
Never stressed
34. How many of your blood relatives have been diagnosed as having cardiovascular disease under the age of 50 years?
>3
3
2
1
none
35. Has your doctor ever said that you have or have had;
a. Heart trouble YES..... NO.....
b. A heart attack YES..... NO.....
c. An abnormal EKG YES..... NO.....
d. A coronary YES..... NO.....
36. Do you have hypoglycaemia or low blood sugar? If so, please explain:
YES..... NO.....
37. Do you drink
a. Coffee YES..... NO.....
b. Soda with caffeine YES..... NO.....
c. Tea YES..... NO.....

38. List any prescribed medications that you are taking: .....
.....
39. List any SELF-PRESCRIBED medications or DIETARY SUPPLEMENTS that you are now taking. These may include vitamins, pain relief tablets, diet pills, antacid medications, etc: .....
40. List any DRUG ALLERGIES: .....

Physical Stats and Exercise Survey:

41. Do you smoke tobacco? YES..... NO.....
42. How much Alcohol do you consume (on average):

Non-drinker.....
1-2 glasses wine or beer/1-2 spirits a week.....
1-2 glasses wine or beer/1-2 spirits a day.....
3-6 beers or glasses of wine/2 sprits drinks per week.....
3-6 beers or glasses of wine/ 2 spirits per day.....
6+ beers or glasses of wine/ more than 2 spirits per week.....
6+ beers or glasses of wine/ more than 2 spirits drinks per day.....

43. Usual exercise frequency:

None.....
1 day per week.....
2-3 days per week.....
4-5 days per week.....
everyday.....

Running History

44. How long have you been running competitively? .....
45. How many days a week do you run? .....
46. What is your typical weekly mileage? .....
47. What is your average distance training run? .....
48. What is the distance of your longest run to date? .....
49. What is your best time for the following running events?

Distance	Time:	Date:
800m	.....	.....
1500m	.....	.....
3000m steeplechase	.....	.....
1 mile	.....	.....
5 Km	.....	.....
10 Km	.....	.....
½ Marathon	.....	.....
Marathon	.....	.....

8.3. Appendix III; Respiratory Measurements Estimates and Norms

SPIROMETRIC VALUES

PREDICTION EQUATIONS FOR NORMAL SPIROMETRIC PARAMETERS FOR MALE SUBJECTS*

	Intercept	Age	Age^2	Ht_{PRD} $(cm)^2$	Ht_{LLN} $(cm)^2$	R^2
Caucasian < 20 yr of age						
FEV_1	−0.7453	−0.04106	0.004477	0.00014098	0.00011607	0.8510
FVC	−0.2584	−0.20415	0.010133	0.00018642	0.00015695	0.8668
PEF	−0.5962	−0.12357	0.013135	0.00024962	0.00017635	0.7808
Caucasian ⩾ 20 yr of age						
FEV_1	0.5536	−0.01303	−0.000172	0.00014098	0.00011607	0.8510
FVC	−0.1933	0.00064	−0.000269	0.00018642	0.00015695	0.8668
PEF	1.0523	0.08272	−0.001301	0.00024962	0.00017635	0.7808
African-American < 20 yr of age						
FEV_1	−0.7048	−0.05711	0.004316	0.00013194	0.00010561	0.8080
FVC	−0.4971	−0.15497	0.007701	0.00016643	0.00013670	0.8303
PEF	−0.2684	−0.28016	0.018202	0.00027333	0.00018938	0.7299
African-American ⩾ 20 yr of age						
FEV_1	0.3411	−0.02309		0.00013194	0.00010561	0.8080
FVC	−0.1517	−0.01821		0.00016643	0.00013670	0.8303
PEF	2.2257	−0.04082		0.00027333	0.00018938	0.7299

Ht_{PRD} coefficient is used for prediction equation and Ht_{LLN} is used (replaces Ht_{PRD}) for the lower limit of normal equation. Lung function parameter = $b_0 + b_1$ age + b_2* age^2 + b_3* $height^2$.

PREDICTION EQUATIONS FOR NORMAL SPIROMETRIC PARAMETERS FOR FEMALE SUBJECTS*

	Intercept	Age	Age^2	Ht_{PRD} $(cm)^2$	Ht_{LLN} $(cm)^2$	R^2
Caucasian < 18 yr of age						
FEV_1	−0.8710	0.06537		0.00011496	0.00009283	0.7494
FVC	−1.2082	0.05916		0.00014815	0.00012198	0.7344
PEF	−3.6181	0.60644	−0.016846	0.00018623	0.00012148	0.5559
Caucasian ⩾ 18 yr of age						
FEV_1	0.4333	−0.00361	−0.000194	0.00011496	0.00009283	0.7494
FVC	−0.3560	0.01870	−0.000382	0.00014815	0.00012198	0.7344
PEF	0.9267	0.06929	−0.001031	0.00018623	0.00012148	0.5559
African-American < 18 yr of age						
FEV_1	−0.9630	0.05799		0.00010846	0.00008546	0.6687
FVC	−0.6166	−0.04687	0.003602	0.00013606	0.00010916	0.6536
PEF	−1.2398	0.16375		0.00019746	0.00012160	0.4736
African-American ⩾ 18 yr of age						
FEV_1	0.3433	−0.01283	−0.000097	0.00010846	0.00008546	0.6687
FVC	−0.3039	0.00536	−0.000265	0.00013606	0.00010916	0.6536
PEF	1.3597	0.03458	−0.000847	0.00019746	0.00012160	0.4736

Ht_{PRD} coefficient is used for prediction equation and Ht_{LLN} is used (replaces Ht_{PRD}) for the lower limit of normal equation. Lung function parameter = $b_0 + b_1$ age + b_2* age^2 * b_3 * $height^2$.

PREDICTION EQUATIONS FOR NORMAL FEV_1/FVC% FOR MALE AND FEMALE SUBJECTS*

	$Intercept_{PRD}$	**Age**	**$Intercept_{LLN}$**	**R^2**
Male subjects				
Caucasian				
FEV_1/FVC%	88.066	–0.2066	78.388	0.3448
African-American				
FEV_1/FVC%	89.239	–0.1828	78.822	0.1538
Female subjects				
Caucasian				
FEV_1/FVC%	90.809	–0.2125	81.015	0.3955
African-American				
FEV_1/FVC%	91.655	–0.2039	80.978	0.2284

*$Intercept_{PRD}$ is used for prediction equation and $Intercept_{LLN}$ is used (replaces $Intercept_{PRD}$) for the lower limit of normal equation. Lung function parameter = $b_0 + b_1$ * age.

(Hankinson *et al.,* 1999).

OXYGEN CONSUMPTION

CARDIORESPIRATORY FITNESS NORMS: VO_2 MAX (ml/kg/min)

Age (yr)	**Poor**	**Fair**	**Good**	**Excellent**	**Superior**
WOMEN					
20-29	≤35	36-39	40-43	44-49	50+
30-39	≤33	34-36	37-40	41-45	46+
40-49	≤31	32-34	35-38	39-44	45+
50-59	≤24	25-28	29-30	31-34	35+
60-69	≤25	26-28	29-31	32-35	36+
70-79	≤23	24-26	27-29	30-35	36+
MEN					
20-29	≤41	42-45	46-50	51-55	56+
30-39	≤40	41-43	44-47	48-53	54+
40-49	≤37	38-41	42-45	46-52	53+
50-59	≤34	35-37	38-42	43-49	50+
60-69	≤30	31-34	35-38	39-45	46+
70-79	≤27	28-30	31-35	36-41	42+

The Cooper Institute for Aerobics Research, as cited by Heyward, (2006 pg. 57).

Oxygen consumption is dependent on the ability to ventilate, the ability of the alveoli to extract oxygen from the air into the blood, the ability of the heart to pump out blood, and the ability of the tissues to extract oxygen from the blood.

$VO_2 = VE \times (.2093 – FEO_2)$

Where: VE = amount of air moved in and out of the lungs/minute

$(.2093 – FEO_2)$ = the amount of O_2 extracted from the air by the lungs

Resting absolute values tend to be around .2-.5L/min in men and .15-.4L/min in women. The approximate resting relative VO_2 for all individuals is 3.5ml/kg*min. Oxygen consumption is most frequently determined using open-circuit spirometry.
The highest absolute VO_2 max values recorded have been in large endurance athletes, such as elite heavyweight rowers (values of over 7L/min have been recorded), whereas the highest relative VO_2 max values are typically recorded in small endurance athletes such as cross-country skiers, cyclists, and distance and middle distance runners (values of up to 90ml/kg/min have been recorded). VO_2 max tests can also be used clinically to assess the type and severity of cardiovascular or pulmonary limitations to exercise.

VO_2 = HR x SV x A-vO_2difference

Where: HR = heart rate in beats per minute
SV = stroke volume (amount of blood pumped out of the heart per beat)
a-vO_2 difference = the amount of O_2 extracted from the blood by the tissues

PULMONARY VENTILATION
At rest most individuals have a VE of 6-10L/min and maximal exercise values (VEmax) are in the range of 100-170 for most individuals. In elite rowers values of up to 250L/min have been recorded. VE increases linearly with VO_2 and workload until about 60% of maximum. Beyond this point it increases at a higher rate.

RESPIRATORY GASSES' PARTIAL PRESSURES
Average Respiratory gasses' partial pressures for a human at rest at near sea level (Plowman & Smith, 1997).

Location	pO_2 (mmHg)	pCO_2 (mmHg)
Outside air (dry air at sea level)	160	0.3
Alveolar air	104 (P_AO_2)	40(P_ACO_2)
Arteriole blood	95 (PaO_2)	40($PaCO_2$)
Venous blood	40	45
Cells	40	45

The factors that determine the values for alveolar pO_2 and pCO_2 are:
The pressure of outside air –barometric pressure
The partial pressures of inspired oxygen and carbon dioxide
The rates of total body oxygen consumption and carbon dioxide production
The rates of alveolar ventilation and perfusion

The alveolar pO_2 is not routinely measured but is calculated from blood gas measurements by the Alveolar gas equation (Curran-Everett, 2006; Martin, 1999).

$$p_AO_2 = F_IO_2(P_{ATM} - pH_2O) - \frac{p_aCO_2(1 - F_IO_2[1 - RQ])}{RQ}$$

where:

Quantity	Description	Sample value
p_AO_2	The alveolar partial pressure of oxygen (pO_2)	107 mmHg (14.2 kPa)
F_IO_2	The fraction of inspired gas that is oxygen (expressed as a decimal).	0.21

P_{ATM}	The prevailing atmospheric pressure	760 mmHg (101 kPa)
pH_2O	The saturated vapour pressure of water at body temperature and the prevailing atmospheric pressure	47 mmHg (6.25 kPa)
p_aCO_2	The arterial partial pressure of carbon dioxide (pCO_2)	36 mmHg (4.79 kPa)
RQ	The respiratory quotient	0.8

Sample Values given for air at sea level at 37°C, at rest.

Arteriole Blood Saturation (SaO_2)
Normal resting value is 98%.
Mild exercise-induced arterial hypoxemia; a fall in SaO_2 to below 95%
Value below 90% causes severe hypoxemia

(Yamaya *et al.,* 2002).

Oxygen Pressure: PaO_2
Since PaO_2 reflects only free oxygen molecules dissolved in plasma and not those bound to hemoglobin, PaO_2 cannot tell us "how much" oxygen is in the blood; for that you need to know how much oxygen is also bound to hemoglobin, information given by the SaO_2 and hemoglobin content.

Oxygen Saturation: SaO_2
The percentage of all the available heme binding sites saturated with oxygen is the hemoglobin oxygen saturation (in arterial blood, the SaO_2). Note that SaO_2 alone doesn't reveal how much oxygen is in the blood; for that we also need to know the hemoglobin content.

Oxygen Content: CaO_2
Tissues need a requisite amount of O_2 molecules for metabolism. Neither the PaO_2 nor the SaO_2 provide information on the number of oxygen molecules, i.e., *how much* oxygen is in the blood. (Neither PaO_2 nor SaO_2 have units that denote any quantity.) Only CaO_2 (units ml O_2/dl) tells us *how much* oxygen is in the blood; this is because CaO_2 is the only value that incorporates the hemoglobin content. Oxygen content can be measured directly or calculated by the oxygen content equation:
$CaO_2 = (Hb \times 1.34 \times SaO_2) + (.003 \times PaO_2)$
(Martin, 1999).

Pressure Units Conversion

1 mmHg	=	1.000000150012 Torr
1 mmHg	=	133.3223684211 pascal
1 mmHg	=	0.133322368421 kPa
1 mmHg	=	1.359510026359 cmH_2O
1 Torr	=	0.999999849988 mmHg
1 kPa	=	7.500616827042 mmHg
1 cmH_2O	=	0.735559121015 mmHg

(Advameg, 2013; ConvertUnits.com, 2013).

8.4. Appendix IV; Test Procedures and Protocols

8.4.1. Appendix IV (a); Spirometry Procedures

For all Spirometry tests, participants will be asked to breathe into a measurement device Spirometer system (ML 311, ADinstruments, Australia) and each test will be repeated at least three times to insure consistency. A complete spirometry exam, including explanation and setup, should take no more than 15 minutes. The three different types of tests are described below:

Forced Vital Capacity (FVC) – participants are instructed to inhale as deeply as possible and then immediately exhale as quickly and as fully as possible, holding the exhalation for 6 seconds at which time subjects will be prompted to take a maximum inhalation.

Slow Vital Capacity (SVC) – participants should take three normal breaths, inhale to maximum lung capacity and then exhale as fully as possible.

Maximum Voluntary Ventilation (MVV) – participants should breathe as deeply and as rapidly as possible for 10 to 12 seconds. Due to the hyperventilation that is forced during this test, it is not uncommon for tests subjects to feel slightly light headed upon completion. This test is always conducted in a seated position.

Key Data Points

• ***FVC*** – Forced Vital Capacity – This is the maximum amount of air that can be expired after a forced maximum inspiration. Forced Vital Capacity is measured in litres (l) and is a measurement of lung volume.

• ***FEV1*** – Forced Expiratory Volume in 1 Second – This is the amount of air that can be forcibly exhaled in the first second of expiration. Again this measurement is taken in litres (l) and is useful in identifying airway functionality.

• ***FEV1/FVC*** – This ratio gives you the percentage of your total lung volume that you are able to exhale within the first second of expiration. In normal lung function this ration should be greater than 75%.

• ***PEF*** – Peak Expiratory Flow – This value is the maximum rate, measured in litres/second (l/s), of expiration that was reached during exhalation. Again this value helps describe airway functionality.

• ***FEF 25% - 75%*** - The average expired flow over the middle half of the FVC and is regarded as a more sensitive measure of small airways narrowing than the FEV_1

Spirometry is a non-invasive and completely painless procedure. Contraindications include; Unstable cardiovascular status, Thoracic/abdominal/cerebral aneurysm, Recent thoracic surgery, Nausea or vomiting, Hemoptysis of unknown origin and Pneumothorax.

(IHF, 2008; Miller *et al.,* 2005; Stanford Human Performance Lab, 2009).

8.4.2. Appendix IV (b); Maximal Inspiratory and Expiratory Pressures

Overview

The Maximal Inspiratory Pressure test (MIP) is designed to determine the maximum pressure the inspiratory muscles can generate. It is normally measured at residual volume (RV). Whereas, the Maximal Expiratory Pressure test (MEP) is designed to determine the maximum pressure the expiratory muscles can generate; it is normally measured at total lung capacity (TLC).

Maximal Inspiratory and Expiratory Pressures (MIP/MEP) measure the strength of the respiratory muscles. The MIP measures the strength of diaphragm whereas the MEP measures the strength of intercostal and abdominal muscles. It is a common practice that MEP is measured at total lung capacity (TLC) and MIP is measured at residual volume (RV). These tests are very effort-dependent and the patient must be well motivated in order to obtain the interpretable results. These tests are normally used to identify muscle weakness or inefficiency as a cause of dyspnea or hypoventilation and should not be routinely performed otherwise.

Instrumentation

The equipment can be as simple as a portable strain gauge or electronic handheld pressure manometer. Most new pulmonary function systems incorporate these tests with simple lung volume level indication to TLC or RV. A typical portable handheld unit (Raytech Instruments, Vancouver, BC) consists of a three-way valve with a 2.5 cm internal diameter. One outlet is open to room air, the other outlet is sealed with a rubber stopper and contains a small hole of 1.0- 2.0 mm inside diameter as a “controlled leak” and 15 mm in length. The purpose of a small hole during the measurement of MIP is to prevent glottic closure as well as facial muscles from generating artificial higher pressure. A rubber mouthpiece and nose clip is also used.

Techniques and Measurements

Participants should sustain maximum pressure for at least one second. Although either peak or sustained pressure can be measured, the Task Force is biased to the measurement of sustained pressures as predictive values are based on sustained pressure measurements.

Place a tight-fitting rubber mouthpiece onto the mouthpiece adapter.

Explain the procedure to the participant; ensure that there is no contraindication for the test.

Instruct the participant to keep a tight lip seal and to give maximum effort.

Maximal Inspiratory Pressure

Ensure that the participant is in the upright sitting position and the “controlled leak” is properly in place.

Place the mouthpiece properly in the participant’s mouth and apply a nose clip.

Instruct the participant to breathe out all the way slowly, and remind the participant to keep the lips tight around the mouthpiece.

When the participant is at residual volume, close shutter and instruct the participant to immediately breathe in as hard as possible for at least 1 second.

A minimum of 3 and a maximum of 8 measurements must be obtained.

If the final effort is the highest value, instruct the participant to perform one more measurement.

The test is said to be reproducible when the highest two values are within 10%.
Depending on the participant, allow the participant to rest for 30 to 60 seconds between tests.

Maximal Expiratory Pressure
Ensure that the subject is in the upright sitting position (the "controlled leak" needs not to be removed as it will not change the lung volumes significantly).
Place the mouthpiece properly in the participant's mouth and apply a nose clip.
Instruct the participant to apply hands to cheeks.
Instruct the participant to breathe in all the way slowly, and remind the participant to keep the lips tight around the mouthpiece.
As soon as the participant cannot breathe in anymore (at TLC level), instruct the participant to immediately push out as hard as possible for at least 1 second.
A minimum of 3 and a maximum of 8 measurements must be obtained. If the final effort is the highest value, instruct the participant to perform one more measurement.
The test is said to be reproducible when the highest two values are within 10%.
Depending on the participant, allow the participant to rest for 30 to 60 seconds between tests.

Indications for test termination
• Syncope
• Angina
• Dizziness/headache/muscle cramping not relieved by rest
• Mental confusion
• Participant requests to stop

Calculations
If a recorder is used, measure the centimeter deflection of the pressure reading and convert to a pressure reading (usually 1 cm deflection = 10 cm H_2O). Measure and record all values sustained for at least 1 second. Report the highest most reproducible, sustained MIP and MEP that meet the acceptability criteria. Results are reported in cm H_2O and compared to predicted values that are based on the same lung volumes as the observed values. If a strain gauge or manometer is used, the only measurement that can be recorded is peak pressure.

Quality Control
Check the calibration of the measurement system with water/mercury manometer or traceable electronic digital pressure monitor each day of use. Ensure that the measurement system reads "zero" at ambient pressure. Using a specialized syringe, apply 100 cm H_2O from the manometer for both negative and positive pressures. The measured reading should be within 5% of the expected value. Adjust the measured reading appropriately to the system or a recorder if required. Pressure transducers must be calibrated quarterly over the range of use ±200 cm H_2O. To accurately interpret the results, poor participant cooperation must be distinguished from actual muscle weakness.

Indications
Indications for this test include the need to:

• identify respiratory muscle weakness as a cause for unexplained dyspnea, hypoventilation or non-parenchymal lung restriction with reduced peak flow or vital capacity
• assess and quantify the respiratory muscle weakness for participants with known neuromuscular diseases (e.g. Guillan-Barré syndrome, myasthenia gravis, polymyositis and amyotrophic lateral sclerosis) or chest deformities (e.g. scoliosis)

Contraindications

MIP/MEP manoeuvres should be performed with caution in the following circumstances:
• recent myocardial infarction (within 4 weeks) or myocarditis
• unstable angina/chest wall pain
• uncontrolled systemic hypertension
• recent pneumothorax
• lung biopsy within previous week
• significant ongoing hemoptysis
• recent eye, abdominal, or spinal surgery

Reporting Guidelines

The report includes:
• results of baseline spirometry
• comments on participant's condition
• technical comments on participant effort
• comparison of participant measurement to predicted normal values
• comments on the significance and relevance of the results to the participant's pathophysiology

(IHF, 2008).

8.4.3. Appendix IV (c); Treadmill Test (Stage I and II Exercise Test)

Overview
Stage I Exercise Test is a progressive, graded power test on treadmill (or a cycle ergometer). The participant exercises until a symptomatic or safety limitation is reached.
Non-invasive parameters such as workload, ventilation, heart rate, oxygen uptake, carbon dioxide output, oxygen saturation, and blood pressure are measured and recorded.
A physician must be in attendance during the Exercise Test.

Instrumentation
Instrumentation used includes a:
• Calibrated cycle ergometer or treadmill (h/p/cosmos COS10199, Germany)
• Mixing chamber or Douglas bags to collect expired ventilation and respiratory gas analysers (17625 and 17626, Vacumed, Ventura, California, USA)
• Blood pressure cuff and sphygmomanometer (BPM-100, VSM Medtech Ltd, Vancouver, Canada)
• Respiratory valves, tubing, noseclip, and mouthpiece
• Flow sensing device (e.g., turbine, pneumotach, pitot tube, mass flow sensor) for measuring ventilation.
• Pulse Oximeter for measuring oxygen saturation
• Computerized system for continuous data acquisition, display and printing of results (PowerLab/16SP, ADInstruments, Colorado Springs, CO)

If a stage 2 test is performed optional equipment includes O_2 and CO_2 analyzers for measuring expired oxygen and carbon dioxide concentrations.
Note: Resuscitation equipment (defibrillator) is mandatory (PowerHeart AED 3G, Cardiac Sciences).

Techniques
A basic standard protocol for stage I exercise testing is widely accepted and is briefly described; ECG electrodes, blood pressure cuff, mouthpiece, and respiratory valve assembly are attached to the subject. Resting measurements are taken. The workload is increased by equal increments every minute. During the last 15 seconds of each minute, all parameters being measured are recorded. The test is continued until the participant is symptom-limited or until the attending physician stops the test.

Measurements
Continuous heart rate, blood pressure, ventilation, expired gas concentration, workload, and oxygen saturation are measured each minute for the duration of the exercise test.

Quality Control
Many of the current exercise systems integrate devices measuring ventilation, expired gases, saturation, heart rate and ECG with either the exercise bicycle or treadmill with a computerized system. As such the test procedures and calibration methodology are usually governed by proprietary algorithms. Nevertheless, minimal calibration requirements apply.

Equipment	Range	Accuracy*	Reproducibility	Frequency Response	Test Signal
		(%)	(%)	(*ms*)	
O2 analyzer	0–100%	1%	1%	< 130	Minimal two-point calibration
CO2 analyzer	0–10%	1%	1%	<130	Minimal two-point calibration
Flow meter	0–14 L/s	3%	3 %	< 40	3-L syringe
Treadmill	0–10 mph	0.2 mph			Timed revolution of marker on belt
	0–20% grade	0.5%			Measurement with carpenter's ruler

* Linearity within the indicated percentage of full scale for each apparatus.

The system must be calibrated daily or prior to testing and includes calibration of the air flow or volume transducer, two point calibration of each gas analyzer with two precision-analyzed gas mixtures (i.e., 5% CO_2 & 12% O_2; 0% CO_2 & 21% O_2). In systems utilizing breath-by-breath gas exchange measurements the delay time between solenoid activation and detection of change in gas analyzer output should also be measured daily. Less frequent calibrations include blood pressure transducers, exercise bicycle or treadmill.

The belt velocity and treadmill grade are tested yearly. For more specific calibration techniques, follow the manufacturer's recommendations.

Note: In older non-integrated systems individual measurement components require specific calibrations.

CO_2 analyzers tend to be alinear so at least a five point calibration between 0 -7% is necessary. Alternatively, a calibration curve can be built using a dilution technique.

CO_2 analyzers are accurate to ± 0.03% of the reading. O_2 analyzers are inherently linear and only require a three point calibration using 0% O_2, 15% O_2, and 100% O_2 with an accuracy of ±0.03%.

The flow sensing device is appropriately calibrated. The respiratory circuit is checked weekly for leaks.

Care must be taken to conduct this test on the same time of the day, as there may be significant diurnal variation, and to use an identical protocol.

(IHF, 2008).

8.4.4. Appendix IV (d); Sampling for Arterial Blood Gas Analysis

Description of the Procedure:
Blood is drawn anaerobically from a peripheral artery (radial) via a single percutaneous needle puncture, or from an indwelling arterial cannula for multiple samples.
Either method provides a blood specimen for direct measurement of partial pressures of carbon dioxide ($PaCO_2$) and oxygen (PaO_2), hydrogen ion activity (pH), total hemoglobin (Hbtotal), oxyhemoglobin saturation (HbO_2), and the dyshemoglobins carboxyhemoglobin (COHb) and methemoglobin (MetHb).
Setting:
Sampling can be performed by trained health care personnel in a variety of settings including (but not limited to) hospitals, clinics, physician offices, extended care facilities, and the home.
Indications:
The need to evaluate the adequacy of ventilator, acid-base, and oxygenation (PaO_2 and SaO_2) status, and the oxygen-carrying capacity of blood (PaO_2, HbO_2, Hbtotal, and dyshemoglobins)
The need to quantitate response to therapeutic intervention and/or diagnostic evaluation (eg, oxygen therapy, exercise testing)
The need to monitor severity and progression of a documented disease process
Contraindications:
Inadequate blood supply to the hand (if indicated by Allan test).
Evidence of infection or peripheral vascular disease involving the selected limb, an alternate site should be selected.
A coagulopathy or medium-to-high-dose anticoagulation therapy (eg, heparin or coumadin, streptokinase, and tissue plasminogen activator but not necessarily aspirin) may be a relative contraindication for arterial puncture.
Possible Complications:
Hematoma, Arteriospasm, Air or clotted-blood emboli, Anaphylaxis from local anesthestic, Introduction of contagion at sampling site and consequent infection in subject,
Introduction of contagion to sampler by inadvertent needle 'stick',
Hemorrhage, Trauma to the vessel, Arterial occlusion, Vasovagal response and Pain
Limitations:
Arterial blood specimens withdrawn from the body only reflect the physiologic condition at the moment of sampling (eg, pain from the puncture itself may lead to hyperventilation with consequent changes in values).
Specimens drawn at peak exercise best reflect response to exercise; however, specimens drawn within 15 seconds or less of termination of exercise may be acceptable (otherwise results do not reflect ventilatory status during dynamic activities and may yield false-negatives for hypoxemic events).
Specimens held at room temperature must be analyzed within 10-15 minutes of drawing; iced samples should be analyzed within 1 hour. The PaO_2 of samples drawn from subjects with elevated white cell counts may decrease very rapidly. Immediate chilling is necessary. Some dual-purpose electrolyte/blood gas analyzers stipulate immediate analysis without chilling because of possible elevations in potassium from chilling; however, the accuracy of the blood gas results should not be affected by the chilling.

Validation of results:
Sample must be obtained anaerobically and anticoagulated, with immediate expulsion of air bubbles. Sample should be immediately chilled or analyzed within 10-15 minutes if left at room temperature.
When a sample is obtained, date, time, participant's body temperature, position, activity level, respiratory rate, sample site, inspired oxygen concentration and mode of ventilation should be documented in the participant's record with the results of blood gas analysis.
Appropriate sample size depends on the anticoagulant used, the requirements of the specific analyzers to be used, and the presence of a need for other assays.
If liquid heparin (sodium or lithium, 1,000 units/mL of blood) is used, excess heparin (all except that filling the dead space of the syringe and needle) should be expelled and a blood sample of 2-4 mL be drawn (liquid heparin dilutes the specimen and changes PCO_2 and PO_2 in direct relationship to the heparin volume).
If lyophilized heparin is used, the minimum volume drawn depends on the design of the analyzers and the need for other assays.
If other assays are required (eg, electrolyte determination), the choice of anticoagulant and the volume of the blood sample should be guided by the analyzer manufacturer's recommendations.
Recommended Equipment:
Single puncture: Appropriate anticoagulant, sterile glass or plastic (low diffusibility) syringe with needle, patient label, 70% isopropyl alcohol or other suitable antiseptic solution, gauze squares or similar material, well-fitting latex or vinyl gloves, puncture-resistant container, syringe cap, 'cork' and device to remove needle from syringe.
Local anesthetic is not generally considered necessary for single punctures.
Indwelling catheter: Sterile glass or plastic (low diffusibility) syringe that has been appropriately anti-coagulated, 'waste' syringe, syringe cap, protective eyewear and outerwear (in the anticipation of splashing), well-fitting latex or vinyl gloves, and patient labels (local anaesthetic is recommended for arterial line insertion)
Container of ice and water (to immerse syringe barrel if specimen will not be analysed within l5 min)
A detailed institutional protocol incorporating current Occupational Health and Safety Administration, and Centers for Disease Control guidelines should be in place
Personnel:
Arterial blood sampling should be performed under the direction of a physician/phlebotomist specifically trained in laboratory medicine, pulmonary medicine, anaesthesia, or critical care.
Two levels of training and experience are recognized for the actual sampling.
Persons designated as Level I should have a high school education plus specific training in sampling arterial blood, oxygen delivery devices and related equipment, recordkeeping, and the associated hazards and sources of specimen and sampler contamination.
Performance of blood sampling should be supervised by a Level-II individual.
The Level-II person is a health care professional trained in patient assessment, acid-base, and oxygenation disorders, and diagnostic and therapeutic alternatives-an associate or higher degree in the sciences or respiratory therapy or substantial experience in pulmonary function technology is preferred. Two years of college with courses in the biologic sciences and mathematics plus 2 years of training and experience may be substituted for personnel supervising arterial blood sampling.

Level-II personnel both sample and supervise Level-I personnel during sampling. A recognized credential (MD, DO, CRTT, RRT, RN, RPFT, CPFT, MT, MLT, RCVT, or equivalent) is strongly recommended.
Monitoring:
The following should be monitored as part of arterial blood sampling:
FIO_2 (analyzed) or prescribed flow rate
Proper application of patient device (eg, mask or cannula)
Pulsatile blood return
Presence or absence of air bubbles or clots in syringe or sample
Participant's respiratory rate
Participant's temperature
Position and/or level of activity (if other than resting)
Ease of (or difficulty with) blood sampling
Appearance of puncture site after direct pressure has been applied and before application of pressure dressing for potential hematoma formation (a detailed protocol for post sampling management should be in place)
Care should be exercised to use alternate sites for participants requiring multiple punctures.
An indwelling catheter may be indicated when multiple sampling is anticipated.
Infection Control:
Universal Precautions as published by the Centers for Disease Control and directives issued by the Department of Labour concerning occupational exposure to blood-borne pathogens must be applied in all circumstances involving blood or blood-contaminated collection devices in the immediate area.
Aseptic technique must be employed whenever blood is sampled from an indwelling arterial catheter.
Prior to a single puncture, the site should be cleaned.
Blood specimens, contaminated needles, and syringes must be disposed of in appropriate containers.
Needles used for blood sampling should be resheathed only with a technique that utilizes a one-hand device or by careful insertion into a cork, rubber plug, or similar device that prevents the sharp point from being accessible.
The needle should be removed from the syringe and the syringe capped.
Gloves provide little protection from needle punctures but should be worn to prevent splashing of blood on sores or other skin breaks.

(Cardipulmonary Diagnostics Guidelines Committee, 1992).

8.4.5. Appendix IV (e); Data Protocol Sheet 1

Participant's Code..... Date.....

Resting physiological measurements –taken at supine resting position

Variable	Ventilation			Respiratory gases partial pressure				ABG measures						Heart rate		Blood pressure	
	Vt	Fb	VE	PO_2	PCO_2	FEO_2	$FECO_2$	PaO_2	$PaCO_2$	SaO_2	pH	HCO3	tHb	HR	%MHR	Systol	Diastol
Value																	
Comments																	

Nomoxic Treadmill Test Trial

Variable Stage	Ventilation			Respiratory gases partial pressure				ABG measures						Heart rate	
	Vt	Fb	VE	PO_2	PCO_2	FEO_2	$FECO_2$	PaO_2	$PaCO_2$	SaO_2	pH	HCO3	tHb	HR	%MHR
1															
2															
3															
4															
5															
6															
Comments															

8.4.6. Appendix IV (f); Data Protocol Sheet 2

Participant's Code..... Date.....

Basic spirometry measurements –taken at sited resting position

Variable	Value 1	Value 2	Value 3	Average	Highest	Comments
Tidal volume (Vt)						
Inspiratory vital capacity (IVC)						
Forced vital capacity (FVC)						
Forced expiratory volume in 1 second (FEV_1)						
FEF 25% - 75%						
Peak expiratory flow rates (PEF)						
Maximal inspiratory (MIP)						
Expiratory pressures (MEP)						
Maximal flow-volume loop (MFVL)						
Maximal voluntary ventilation (MVV) in 12 sec.						

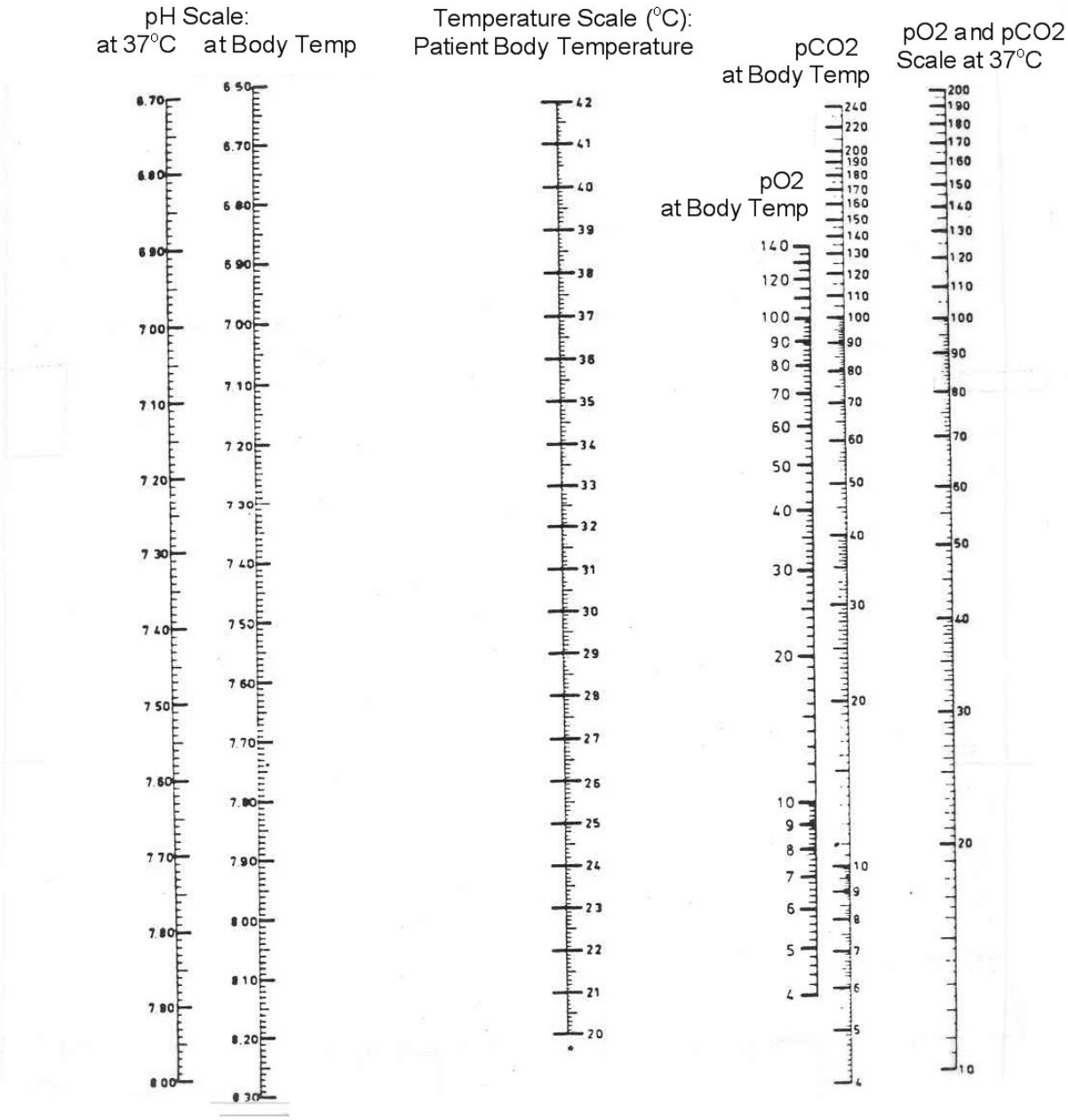
8.4.7. Appendix IV (g); Data Protocol Sheet 3

Participant's Code..... Date.....

Basic anthropometric measurements –Adapted ISAK Proforma

Variable	Value	Comments
Sex (male=1, female=2)		
Sport/Event		
Date of Birth		
Body mass		
Stretch stature		
Triceps skin fold		
Subscapular skin fold		
Biceps skin fold		
Iliac Crest skin fold		
Supraspinale skin fold		
Abdominal skin fold		
Front Thigh skin fold		
Medial Calf skin fold		
Arm girth relaxed		
Corrected arm girth		
Arm girth flexed and tensed		
Waist girth (min.)		
Gluteal girth (max.)		
Calf girth (max.)		
Corrected calf girth (max.)		
Humerus breadth (biepicondylar)		
Femur breadth (biepicondylar)		

8.5. Appendix V; Nomogram for Correcting ABG Data to Body Temperature



NOMOGRAM for correcting arterial blood gas data (pH, pCO_2, pO_2) to body temperature

Correcting Arterial Blood Gas Data (pH, pCO2, pO2) to Body Temperature

Sometimes a physician may want to know what the blood gas results of his patient/subject are related to the patient/subject's actual body temperature. The patient/subject may have a fever or be severely hypothermic.

Most blood gas analyzers are equipped with software that can 'correct' the 37°C analyzer values to the patient/subject's actual body temperature, or we can use a nomogram such as the one on the previous page. In all instances, the 37°C arterial blood gas results are reported to the patient/subject's chart and medical record. A notation is added and documentation made of the 'corrected' blood gas values related to the patient/subject's body temperature.

Example: Correct the arterial blood gas values analyzed at 37°C to the body temperature of the patient (39°C) when the blood gases were drawn.

Values obtained from blood gas analyzer (temperature: 37°C)

pCO_2: 60 mmHg
pO_2: 80 mmHg
pH: 7.40

Step 1: Place a dot on the 'Temperature Scale: Patient Body Temp' at 39°C (the patient/subject's actual body temperature).
Step 2: Correct the pH value of 7.40 by placing a dot on the 'pH Scale at 37°C' (the analyzer temperature) at 7.40
Step 3: Draw a line connecting these two dots. Read the corrected pH value from the 'pH Scale: at Body Temp' and record the corrected value below
Step 4: To correct the pO_2 value, place a dot on the 'pO_2 and pCO_2 Scale at 37°C' at 80 (the value obtained from the analyzer at 37°C)
Step 5: Draw a line connecting the pO_2 dot to the patient/subject body temp of 39°C (from step 1) on the 'Temperature Scale'. Read the corrected pO_2 from the 'pO_2 at Body Temp' scale and record the corrected value below
Step 6: To correct the pCO_2 value, place a dot on the 'pO_2 and pCO_2 Scale at 37°C' at 60 (the value obtained from the analyzer at 37°C)
Step 7: Draw a line connecting the pCO_2 dot to the patient/subject body temp of 39°C (from step 1) on the 'Temperature Scale'. Read the corrected pCO_2 from the 'pCO_2 at Body Temp' scale and record the corrected value below:

Blood Gas Parameter	Values obtained from blood gases analyzed at 37°C	Corrected values reflecting patient/ subject's body temperature of 39°C
pCO_2	60 mmHg	
pO_2	80 mmHg	
pH	7.40	

CLS 414 Chemistry Clinical Rotation I Unit 3 Nomogram (pH, pCO2, pO2), Clinical Laboratory Sciences

(University of Nebraska Medical Center, 2010).

8.6. Appendix VI; Sphericity Adjustments and Intraclass Correlation Tests

Minute ventilation (VE)

Table 4.17d: Test of sphericity for minute ventilation (VE) in three exercise stages leading to maximal endurance treadmill run (*n* =14).

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	*df*	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise Stage	.459	9.341	2	.009	.649	.691	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table 4.17e: Tests of within-subjects effects comparing minute ventilation (VE) for three exercise stages leading to maximal endurance treadmill run (*n* =14).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Squared	Observed Power[a]
ExerciseStage	Sphericity Assumed	806.924	2	403.462	19.854	.000	.604	1.000
	Greenhouse-Geisser	806.924	1.298	621.677	19.854	.000	.604	.996
	Huynh-Feldt	806.924	1.382	583.898	19.854	.000	.604	.997
	Lower-bound	806.924	1.000	806.924	19.854	.001	.604	.984
Error (ExerciseStage)	Sphericity Assumed	528.368	26	20.322				
	Greenhouse-Geisser	528.368	16.874	31.313				
	Huynh-Feldt	528.368	17.965	29.410				
	Lower-bound	528.368	13.000	40.644				

a. Computed using alpha = .05

Table 4.17f: Intraclass correlation coefficient reliability test for minute ventilation (VE) in three exercise stages leading to maximal endurance treadmill run (*n* =14).

	Intraclass Correlation[a]	95% Confidence Interval		*F* Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.924[b]	.826	.972	37.259	13	26	.000
Average Measures	.973[c]	.934	.991	37.259	13	26	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 4.17g: Tests of within-subjects effects comparing sub-maximal, maximal and peak (highest recorded) minute ventilation (VE) values *(n* = 14).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
Exercise Stage	Sphericity Assumed	152.278	2	76.139	8.601	.001	.398	.948
	Greenhouse-Geisser	152.278	1.226	124.182	8.601	.007	.398	.835
	Huynh-Feldt	152.278	1.288	118.206	8.601	.006	.398	.849
	Lower-bound	152.278	1.000	152.278	8.601	.012	.398	.774
Error (Exercise Stage)	Sphericity Assumed	230.154	26	8.852				
	Greenhouse-Geisser	230.154	15.941	14.438				
	Huynh-Feldt	230.154	16.747	13.743				
	Lower-bound	230.154	13.000	17.704				

Breathing Frequency (Fb)

Table 4.18d: Test of sphericity for breathing frequency (Fb) in three exercise stages leading to maximal endurance treadmill run (*n* =14).

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	*df*	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise Stage	.735	3.698	2	.157	.790	.881	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table 4.18e: Tests of within-subjects effects comparing breathing frequency (Fb) for three exercise stages leading to maximal endurance treadmill run (*n* =14).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Squared	Observed Power[a]
ExerciseStage	Sphericity Assumed	79.996	2	39.998	5.191	.013	.285	.782
	Greenhouse-Geisser	79.996	1.581	50.607	5.191	.021	.285	.705
	Huynh-Feldt	79.996	1.763	45.379	5.191	.017	.285	.741
	Lower-bound	79.996	1.000	79.996	5.191	.040	.285	.559
Error(ExerciseStage)	Sphericity Assumed	200.323	26	7.705				
	Greenhouse-Geisser	200.323	20.550	9.748				
	Huynh-Feldt	200.323	22.917	8.741				
	Lower-bound	200.323	13.000	15.409				

a. Computed using alpha = .05

Table 4.18f: Intraclass reliability test for breathing frequency (Fb) in three exercise stages leading to maximal endurance treadmill run (*n* =14).

	Intraclass Correlation[a]	95% Confidence Interval		*F* Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.930[b]	.839	.975	40.846	13	26	.000
Average Measures	.976[c]	.940	.991	40.846	13	26	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 4.18g: Tests of within-subjects effects comparing sub-maximal, maximal and peak (highest recorded) breathing frequency (Fb) values (*n* = 14).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
ExerciseStage	Sphericity Assumed	48.668	2	24.334	6.644	.005	.338	.878
	Greenhouse-Geisser	48.668	1.273	38.237	6.644	.015	.338	.742
	Huynh-Feldt	48.668	1.349	36.079	6.644	.013	.338	.761
	Lower-bound	48.668	1.000	48.668	6.644	.023	.338	.664
Error (ExerciseStage)	Sphericity Assumed	95.221	26	3.662				
	Greenhouse-Geisser	95.221	16.546	5.755				
	Huynh-Feldt	95.221	17.536	5.430				
	Lower-bound	95.221	13.000	7.325				

a. Computed using alpha = .05

Respiratory Exchange Ratio (RER)

Table 4.19d: Test of sphericity for respiratory exchange ratio (RER) in three exercise stages leading to maximal endurance treadmill run (*n* =14).

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	*df*	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise Stage	.360	12.260	2	.002	.610	.640	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table 4.19e: Tests of within-subjects effects comparing respiratory exchange ratio (RER) for three exercise stages leading to maximal endurance treadmill run (*n* =14).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Squared	Observed Power[a]
Exercise Stage	Sphericity Assumed	.017	2	.009	27.145	.000	.676	1.000
	Greenhouse-Geisser	.017	1.220	.014	27.145	.000	.676	.999
	Huynh-Feldt	.017	1.279	.013	27.145	.000	.676	1.000
	Lower-bound	.017	1.000	.017	27.145	.000	.676	.998
Error (ExerciseStage)	Sphericity Assumed	.008	26	.000				
	Greenhouse-Geisser	.008	15.854	.001				
	Huynh-Feldt	.008	16.633	.000				
	Lower-bound	.008	13.000	.001				

a. Computed using alpha = .05

Table 4.19f: Intraclass correlation coefficient reliability test for respiratory exchange ratio (RER) in three exercise stages leading to maximal endurance treadmill run (*n* =14).

		95% Confidence Interval		*F* Test with True Value 0			
	Intraclass Correlation[a]	Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.932[b]	.844	.976	42.291	13	26	.000
Average Measures	.976[c]	.942	.992	42.291	13	26	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 4.19g: Tests of within-subjects effects comparing sub-maximal, maximal and peak (highest recorded) respiratory exchange ratio (RER) values (*n* = 14).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
Exercise Stage	Sphericity Assumed	.005	2	.002	24.613	.000	.654	1.000
	Greenhouse-Geisser	.005	1.051	.004	24.613	.000	.654	.997
	Huynh-Feldt	.005	1.065	.004	24.613	.000	.654	.997
	Lower-bound	.005	1.000	.005	24.613	.000	.654	.995
Error (ExerciseStage)	Sphericity Assumed	.002	26	9.427E-5				
	Greenhouse-Geisser	.002	13.669	.000				
	Huynh-Feldt	.002	13.840	.000				
	Lower-bound	.002	13.000	.000				

a. Computed using alpha = .05

Oxygen consumption (VO_2)

Table 4.21d: Test of sphericity for relative oxygen consumption rate (rVO_2) in three exercise stages leading to maximal endurance treadmill run (n =14).

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	*df*	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise Stage	.468	9.120	2	.010	.653	.696	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table 4.21e: Tests of within-subjects effects comparing relative oxygen consumption rate for three exercise stages leading to maximal endurance treadmill run (n =14).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Squared	Observed Power[a]
ExerciseStage	Sphericity Assumed	210.194	2	105.097	10.878	.000	.456	.982
	Greenhouse-Geisser	210.194	1.305	161.043	10.878	.002	.456	.924
	Huynh-Feldt	210.194	1.391	151.059	10.878	.002	.456	.936
	Lower-bound	210.194	1.000	210.194	10.878	.006	.456	.861
Error (ExerciseStage)	Sphericity Assumed	251.187	26	9.661				
	Greenhouse-Geisser	251.187	16.968	14.804				
	Huynh-Feldt	251.187	18.089	13.886				
	Lower-bound	251.187	13.000	19.322				

a. Computed using alpha = .05

Table 4.21f: Intraclass correlation coefficients reliability test for relative oxygen consumption rate (rVO_2) in three exercise stages leading to maximal endurance treadmill run (n =14).

	Intraclass Correlation[a]	95% Confidence Interval		*F* Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.874[b]	.725	.954	21.805	13	26	.000
Average Measures	.954[c]	.888	.984	21.805	13	26	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 4.21g: Tests of within-subjects effects comparing sub-maximal, maximal and peak (highest recorded) relative oxygen consumption rate (rVO_2) values (n = 14).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Squared	Observed Power[a]
Exercise Stage	Sphericity Assumed	24.432	2	12.216	3.836	.035	.228	.644
	Greenhouse-Geisser	24.432	1.320	18.515	3.836	.057	.228	.515
	Huynh-Feldt	24.432	1.410	17.323	3.836	.053	.228	.534
	Lower-bound	24.432	1.000	24.432	3.836	.072	.228	.442
Error (Exercise Stage)	Sphericity Assumed	82.787	26	3.184				
	Greenhouse-Geisser	82.787	17.154	4.826				
	Huynh-Feldt	82.787	18.335	4.515				
	Lower-bound	82.787	13.000	6.368				

a. Computed using alpha = .05

pH Values

Table 4.31d: Test of sphericity for pH values in three exercise stages leading to maximal endurance treadmill run (n =12).

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	*df*	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise Stage	.326	11.212	2	.004	.597	.629	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table 4.31e: Tests of within-subjects effects comparing pH values for three exercise stages leading to maximal endurance treadmill run (n =12).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Squared	Observed Power[a]
Exercise Stage	Sphericity Assumed	.014	2	.007	16.340	.000	.598	.999
	Greenhouse-Geisser	.014	1.195	.011	16.340	.001	.598	.977
	Huynh-Feldt	.014	1.258	.011	16.340	.001	.598	.982
	Lower-bound	.014	1.000	.014	16.340	.002	.598	.956
Error (ExerciseStage)	Sphericity Assumed	.009	22	.000				
	Greenhouse-Geisser	.009	13.141	.001				
	Huynh-Feldt	.009	13.839	.001				
	Lower-bound	.009	11.000	.001				

a. Computed using alpha = .05

Table 4.31f: Intraclass correlation coefficient reliability test for pH values in three exercise stages leading to maximal endurance treadmill run (*n* =12).

	Intraclass Correlation[a]	95% Confidence Interval		*F* Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.925[b]	.816	.976	37.928	11	22	.000
Average Measures	.974[c]	.930	.992	37.928	11	22	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 4.31g: Tests of within-subjects effects comparing sub-maximal, maximal and extreme pH values values (*n* = 12).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
Execise Stage	Sphericity Assumed	.005	2	.003	10.762	.001	.495	.979
	Greenhouse-Geisser	.005	1.124	.005	10.762	.005	.495	.879
	Huynh-Feldt	.005	1.163	.004	10.762	.005	.495	.887
	Lower-bound	.005	1.000	.005	10.762	.007	.495	.847
Error (ExeciseStage)	Sphericity Assumed	.005	22	.000				
	Greenhouse-Geisser	.005	12.361	.000				
	Huynh-Feldt	.005	12.791	.000				
	Lower-bound	.005	11.000	.000				

a. Computed using alpha = .05

Bicarbonate Ions (HCO_3)

Table 4.32d: Test of sphericity for bicarbonate ions (HCO_3) in three exercise stages leading to maximal endurance treadmill run (*n* =12).

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	*df*	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise Stage	.482	7.291	2	.026	.659	.713	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table 4.32e: Tests of within-subjects effects comparing bicarbonate ions (HCO_3) for three exercise stages leading to maximal endurance treadmill run (n =12).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
Exercise Stage	Sphericity Assumed	25.376	2	12.688	28.790	.000	.724	1.000
	Greenhouse-Geisser	25.376	1.318	19.256	28.790	.000	.724	1.000
	Huynh-Feldt	25.376	1.427	17.786	28.790	.000	.724	1.000
	Lower-bound	25.376	1.000	25.376	28.790	.000	.724	.998
Error (ExerciseStage)	Sphericity Assumed	9.696	22	.441				
	Greenhouse-Geisser	9.696	14.496	.669				
	Huynh-Feldt	9.696	15.694	.618				
	Lower-bound	9.696	11.000	.881				

a. Computed using alpha = .05

Table 4.32f: Intraclass correlation coefficient reliability test for bicarbonate ions (HCO_3) in three exercise stages leading to maximal endurance treadmill run (n =12).

	Intraclass Correlation[a]	95% Confidence Interval		*F* Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.946[b]	.865	.983	53.372	11	22	.000
Average Measures	.981[c]	.950	.994	53.372	11	22	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 4.32g: Tests of within-subjects effects comparing sub-maximal, maximal and extreme bicarbonate ions (HCO_3) values (n = 12).

Source		Type III Sum of Squares	*df*	Mean Sq.	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
Execise Stage	Sphericity Assumed	9.976	2	4.988	25.002	.000	.694	1.000
	Greenhouse-Geisser	9.976	1.002	9.958	25.002	.000	.694	.995
	Huynh-Feldt	9.976	1.002	9.952	25.002	.000	.694	.995
	Lower-bound	9.976	1.000	9.976	25.002	.000	.694	.995
Error (ExeciseStage)	Sphericity Assumed	4.389	22	.200				
	Greenhouse-Geisser	4.389	11.020	.398				
	Huynh-Feldt	4.389	11.026	.398				
	Lower-bound	4.389	11.000	.399				

a. Computed using alpha = .05

Arterial blood oxygen saturation (SaO_2)

Table 4.33d: Test of sphericity for arterial blood oxygen saturation (SaO_2) in three exercise stages leading to maximal endurance treadmill run (*n* =12).

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	*df*	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise Stage	.480	7.342	2	.025	.658	.712	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table 4.33e: Tests of within-subjects effects comparing arterial blood oxygen saturation for three exercise stages leading to maximal endurance treadmill run (*n* =12).

Source		Type III Sum of Squares	*df*	Mean Sq.	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
Exercise Stage	Sphericity Assumed	34.429	2	17.214	18.547	.000	.628	1.000
	Greenhouse-Geisser	34.429	1.316	26.168	18.547	.000	.628	.993
	Huynh-Feldt	34.429	1.424	24.181	18.547	.000	.628	.995
	Lower-bound	34.429	1.000	34.429	18.547	.001	.628	.974
Error (ExerciseStage)	Sphericity Assumed	20.420	22	.928				
	Greenhouse-Geisser	20.420	14.473	1.411				
	Huynh-Feldt	20.420	15.662	1.304				
	Lower-bound	20.420	11.000	1.856				

a. Computed using alpha = .05

Table 4.33f: Intraclass correlation coefficient reliability test for arterial blood oxygen saturation in three exercise stages leading to maximal endurance treadmill run (*n* =12).

	Intraclass Correlation[a]	95% Confidence Interval		*F* Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.944[b]	.861	.982	51.834	11	22	.000
Average Measures	.981[c]	.949	.994	51.834	11	22	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 4.33g: Tests of within-subjects effects comparing sub-maximal, maximal and extreme arterial blood oxygen saturation (SaO_2) values (n = 12).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
Exercise Stage	Sphericity Assumed	17.648	2	8.824	11.250	.000	.506	.983
	Greenhouse-Geisser	17.648	1.103	16.000	11.250	.005	.506	.888
	Huynh-Feldt	17.648	1.135	15.545	11.250	.004	.506	.895
	Lower-bound	17.648	1.000	17.648	11.250	.006	.506	.862
Error (ExerciseStage)	Sphericity Assumed	17.257	22	.784				
	Greenhouse-Geisser	17.257	12.133	1.422				
	Huynh-Feldt	17.257	12.489	1.382				
	Lower-bound	17.257	11.000	1.569				

a. Computed using alpha = .05

Alveolar to arterial oxygen difference ($AaDO_2$)

Table 4.34d: Test of sphericity for alveolar to arterial blood oxygen difference for three exercise stages leading to maximal endurance treadmill run (n =12).

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	*df*	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise Stage	.307	11.810	2	.003	.591	.620	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table 4.34e: Tests of within-subjects effects comparing alveolar to arterial blood oxygen difference for three exercise stages leading to maximal endurance treadmill run (n =12).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
Exercise Stage	Sphericity Assumed	84.787	2	42.394	7.915	.003	.418	.923
	Greenhouse-Geisser	84.787	1.181	71.773	7.915	.012	.418	.780
	Huynh-Feldt	84.787	1.240	68.373	7.915	.011	.418	.796
	Lower-bound	84.787	1.000	84.787	7.915	.017	.418	.726
Error (ExerciseStage)	Sphericity Assumed	117.829	22	5.356				
	Greenhouse-Geisser	117.829	12.995	9.068				
	Huynh-Feldt	117.829	13.641	8.638				
	Lower-bound	117.829	11.000	10.712				

a. Computed using alpha = .05

Table 4.34f: Intraclass correlation coefficient reliability test for alveolar to arterial blood oxygen difference for three exercise stages leading to maximal endurance treadmill run (*n* =12).

	Intraclass Correlation[a]	95% Confidence Interval		*F* Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.863[b]	.685	.954	19.919	11	22	.000
Average Measures	.950[c]	.867	.984	19.919	11	22	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 4.34g: Tests of within-subjects effects comparing sub-maximal, maximal and extreme alveolar to arterial blood oxygen difference ($AaDO_2$) values (*n* = 12).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
Exercise Stage	Sphericity Assumed	38.678	2	19.339	10.255	.001	.482	.973
	Greenhouse-Geisser	38.678	1.037	37.308	10.255	.008	.482	.840
	Huynh-Feldt	38.678	1.048	36.910	10.255	.007	.482	.843
	Lower-bound	38.678	1.000	38.678	10.255	.008	.482	.830
Error (ExerciseStage)	Sphericity Assumed	41.486	22	1.886				
	Greenhouse-Geisser	41.486	11.404	3.638				
	Huynh-Feldt	41.486	11.527	3.599				
	Lower-bound	41.486	11.000	3.771				

a. Computed using alpha = .05

Total Haemoglobin (tHb)

Table 4.35d: Test of sphericity for total hemoglobin (tHb) for three exercise stages leading to maximal endurance treadmill run (*n* =12).

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	*df*	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise Stage	.878	1.304	2	.521	.891	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table 4.35e: Tests of within-subjects effects comparing total hemoglobin (tHb) for three exercise stages leading to maximal endurance treadmill run (*n* =12).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
Exercise Stage	Sphericity Assumed	.377	2	.189	5.464	.012	.332	.794
	Greenhouse-Geisser	.377	1.782	.212	5.464	.015	.332	.757
	Huynh-Feldt	.377	2.000	.189	5.464	.012	.332	.794
	Lower-bound	.377	1.000	.377	5.464	.039	.332	.568
Error (ExerciseStage)	Sphericity Assumed	.759	22	.035				
	Greenhouse-Geisser	.759	19.603	.039				
	Huynh-Feldt	.759	22.000	.035				
	Lower-bound	.759	11.000	.069				

a. Computed using alpha = .05

Table 4.35f: Intraclass correlation coefficient reliability test for total hemoglobin (tHb) for three exercise stages leading to maximal endurance treadmill run (*n* =12).

	Intraclass Correlation[a]	95% Confidence Interval		*F* Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.981[b]	.951	.994	156.546	11	22	.000
Average Measures	.994[c]	.983	.998	156.546	11	22	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 4.35g: Tests of within-subjects effects comparing sub-maximal, maximal and extreme total hemoglobin (tHb) values (*n* = 12).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
Exercise Stage	Sphericity Assumed	.712	2	.356	5.938	.009	.351	.828
	Greenhouse-Geisser	.712	1.836	.388	5.938	.011	.351	.802
	Huynh-Feldt	.712	2.000	.356	5.938	.009	.351	.828
	Lower-bound	.712	1.000	.712	5.938	.033	.351	.603
Error (ExerciseStage)	Sphericity Assumed	1.318	22	.060				
	Greenhouse-Geisser	1.318	20.193	.065				
	Huynh-Feldt	1.318	22.000	.060				
	Lower-bound	1.318	11.000	.120				

a. Computed using alpha = .05

Oxygen Content (CaO_2)

Table 4.36d: Test of sphericity for oxygen content (CaO_2) for three exercise stages leading to maximal endurance treadmill run (n =12).

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	*df*	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Exercise Stage	.800	2.227	2	.328	.834	.965	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table 4.36e: Tests of within-subjects effects comparing oxygen content (CaO_2) for three exercise stages leading to maximal endurance treadmill run (n =12) (stage 3-5).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
Exercise Stage	Sphericity Assumed	.159	2	.080	.856	.439	.072	.178
	Greenhouse-Geisser	.159	1.667	.095	.856	.422	.072	.165
	Huynh-Feldt	.159	1.929	.082	.856	.436	.072	.175
	Lower-bound	.159	1.000	.159	.856	.375	.072	.135
Error (ExerciseStage)	Sphericity Assumed	2.046	22	.093				
	Greenhouse-Geisser	2.046	18.339	.112				
	Huynh-Feldt	2.046	21.223	.096				
	Lower-bound	2.046	11.000	.186				

a. Computed using alpha = .05

Table 4.36f: Intraclass correlation coefficient reliability test for oxygen content (CaO_2) for three exercise stages leading to maximal endurance treadmill run (n =12).

	Intraclass Correlation[a]	95% Confidence Interval		*F* Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.962[b]	.902	.988	76.107	11	22	.000
Average Measures	.987[c]	.965	.996	76.107	11	22	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 4.36g: Tests of within-subjects effects comparing sub-maximal, maximal and extreme (lowest) oxygen content (CaO_2) values (n = 12).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
Exercise Stage	Sphericity Assumed	1.644	2	.822	11.948	.000	.521	.988
	Greenhouse-Geisser	1.644	1.618	1.016	11.948	.001	.521	.970
	Huynh-Feldt	1.644	1.857	.885	11.948	.000	.521	.983
	Lower-bound	1.644	1.000	1.644	11.948	.005	.521	.882
Error (ExerciseStage)	Sphericity Assumed	1.513	22	.069				
	Greenhouse-Geisser	1.513	17.801	.085				
	Huynh-Feldt	1.513	20.424	.074				
	Lower-bound	1.513	11.000	.138				

a. Computed using alpha = .05

Table 4.36h: Tests of within-subjects effects comparing sub-maximal, maximal and extreme (peak) oxygen content (CaO_2) values (n = 12).

Source		Type III Sum of Squares	*df*	Mean Square	*F*	Sig.	Partial Eta Sqd.	Observed Power[a]
Exercise Stage	Sphericity Assumed	1.795	2	.898	6.420	.006	.369	.858
	Greenhouse-Geisser	1.795	1.835	.978	6.420	.008	.369	.833
	Huynh-Feldt	1.795	2.000	.898	6.420	.006	.369	.858
	Lower-bound	1.795	1.000	1.795	6.420	.028	.369	.637
Error (ExerciseStage)	Sphericity Assumed	3.076	22	.140				
	Greenhouse-Geisser	3.076	20.188	.152				
	Huynh-Feldt	3.076	22.000	.140				
	Lower-bound	3.076	11.000	.280				

a. Computed using alpha = .05